40 CFR Part 191
Subparts B and C
Compliance Recertification Application 2026
for the
Waste Isolation Pilot Plant

Appendix MASS-2026
Performance Assessment
Modeling Assumptions

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Field Office
Carlsbad, New Mexico

Compliance Recertification Application 2026
Appendix MASS

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ACRONYMS AND ABBREVIATIONS

APPA	Additional Panels Performance Assessment
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CCMPR	Changed Conceptual Models Peer Review
CFR	Code of Federal Regulations
CH	contact-handled
cm	centimeters
CPR	cellulosic, plastic, and rubber
CRA	Compliance Recertification Application
DBR	direct brine release
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
EXP	experimental area/region
FEP	feature, event, and process
ft	foot
in.	inch
K_d	Culebra matrix partition coefficient
LWA	Land Withdrawal Act
m	meter
MB	marker bed
MPa	megapascals
NROR	north rest of repository
OPS	operations area/region
PA	performance assessment
PABC	Performance Assessment Baseline Calculation
PAVT	Performance Assessment Verification Test
pH	measure of the acidity or alkalinity of a solution
RH	remote-handled
ROMPCS	Run-of-Mine Panel Closure System

SOPS	south operations area/region
SROR	south rest of repository
T-field	transmissivity field
TRU	transuranic
WD	west drifts region
WIPP	Waste Isolation Pilot Plant
WOPS	west operations area/region
WP	waste panel region of model for Salado flow
WROR	west rest of repository

ELEMENTS AND CHEMICAL COMPOUNDS

Am	americium
$CaCO_3$	calcite
Cm	curium
CO_2	carbon dioxide
Fe	iron
H_2	hydrogen
H_2S	hydrogen sulfide
$Mg(OH)_2$	brucite, magnesium hydroxide
$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$	hydromagnesite
MgO	magnesium oxide
Np	neptunium
$PbCO_3$	cerrusite
Pu	plutonium
Th	thorium
U	uranium

MASS-1.0 INTRODUCTION

This appendix presents supplementary information regarding the assumptions, simplifications, and approximations used in models that form the basis of the 2026 Compliance Recertification Application (CRA-2026) performance assessment (PA) of the Waste Isolation Pilot Plant (WIPP). The PA executed in support of the fifth WIPP recertification is denoted as the "CRA-2026 PA"[1]. Within this appendix, relevant issues in the formulation or development of the various types of models (for example, conceptual, mathematical, numerical, or computer code) used for the topic under consideration in each section are discussed, and references to relevant historical information are included where appropriate.

This appendix references the Compliance Certification Application (CCA) (U.S. DOE 1996), the 2004 Compliance Recertification Application (CRA-2004) (U.S. DOE 2004), the 2009 Compliance Recertification Application (CRA-2009) (U.S. DOE 2009), the 2014 Compliance Recertification Application (CRA-2014) (U.S. DOE 2014), and the 2019 Compliance Recertification Application (CRA-2019) (U.S. DOE 2019) when the information discussed has not changed from past demonstrations of compliance with the U.S. Environmental Protection Agency's (EPA's) disposal standards. Historical development of the WIPP conceptual models is documented in the CCA, Appendix MASS-2.0; Appendix PA-2004, Attachment MASS; Appendix MASS-2009; Appendix MASS-2014; and Appendix MASS-2019. Since the CRA-2019 PA, a reference document has been issued (McCormick et al. 2024) that describes the conceptual models used in the WIPP PA. This document also chronicles the history of changes to each conceptual model, including those associated with the 2021 Additional Panels Performance Assessment (APPA) Changed Conceptual Models Peer Review (CCMPR) (Falta et al. 2021).

Several changes have been incorporated in the CRA-2026 PA in relation to the CRA-2019. The modifications in the CRA-2026 PA include parameter updates and refinements to PA implementation. A summary of changes in PA since the CRA-2019 is given in the Appendix PA-2026. Appendix MASS-2.0 includes a discussion of general modeling assumptions applicable to the disposal system as a whole, including a table of assumptions made in PA models, with cross-references. The remainder of this appendix discusses assumptions specific to the conceptual models used in the CRA-2026 PA.

MASS-2.0 GENERAL ASSUMPTIONS IN PA MODELS

Several assumptions are generally applied to the disposal system through the conceptual and mathematical models implemented in the CRA-2026 PA. Table MASS-1 through Table MASS-65 list modeling assumptions used in the PA. Because many of the assumptions have not changed from earlier CRA submittals, material submitted with those recertification applications is listed for reference. References to documents included in the CRA-2026 are also included where

[1] Two PA analyses are documented as part of the CRA-2026 submittal. The CRA26_IS analysis, which considers a 12-panel "interim" repository representation, is the primary analysis and is referred to as the "CRA-2026 PA" in this document. The supplemental analysis CRA26_FS, which considers a 19-panel "final" repository representation, is documented in Appendix PA, Attachment Supplemental Final State.

appropriate. These tables provide guidance for integrating the assumptions with (1) the chapters, sections, or appendices in which they are discussed, and (2) the codes that implement them. The codes are: BRAGFLO (brine and gas flow in and around the Salado Formation, as well as direct brine release [DBR] volume calculation), MODFLOW6 (brine flow in the Culebra Formation), SECOTP2D (radionuclide transport in the Culebra Formation), DRSPALL (spallings releases), PEST++ (parameter estimation), SIERRA_SolidMechanics (Sierra_SM) (creep closure calculation), NUTS (radionuclide transport in and around the Salado Formation), PANEL (radionuclide concentrations), CUTTINGS_S (cuttings and cavings volumes), and CCDFGF (stochastic future calculation and complementary cumulative distribution function [CCDF] assembly).

The features, events, and processes (FEPs) discussed in Appendix SCR-2026 that are relevant to these assumptions are also indicated. The final column in the tables indicates whether each assumption is considered reasonable or conservative. The overall results of PA have not been biased toward a conservative outcome. However, conservative assumptions have been used when data or models are impractical to obtain, or when effects on performance are not expected to be significant enough to justify the development of a more complicated model. In all other cases, the best unbiased conceptual models and parameter values have been selected. The designator R (reasonable) in the final column indicates that the assumption is considered to be reasonable based on WIPP-specific data or information, data or information considered analogous to the WIPP disposal system, expert judgment, or other reasoning. The designator C (conservative) indicates that the assumption (i.e., model inputs) may overestimate a process or effect.[2] The regulatory designator (Reg) indicates that the assumption is based on regulations in 40 Code of Federal Regulations (CFR) Part 191, criteria in 40 CFR Part 194, or other regulatory guidance.

[2] Conservatism in some model inputs may result in lower or higher releases.

Table MASS-1. General Modeling Assumptions 1–6

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
1	BRAGFLO MODFLOW6	Flow is governed by mass conservation and Darcy's Law in the porous media. Flow is laminar and fluids are Newtonian.	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24) Brine Inflow (W40)	R
2	BRAGFLO	Two-phase flow in the porous media is by simultaneous immiscible displacement.	Fluid Flow Due to Gas Production (W42)	R
3	BRAGFLO	The Brooks-Corey or Van Genuchten/Parker equations represent interactions between brine and gas.	Fluid Flow Due to Gas Production (W42)	R
4	BRAGFLO	The Klinkenberg effect is included for the flow of gases at low pressures.	Fluid Flow Due to Gas Production (W42)	R
5	BRAGFLO	Threshold displacement pressure for the flow of gas into brine is constant.	Fluid Flow Due to Gas Production (W42)	R
6	BRAGFLO MODFLOW6 SECOTP2D	Fluid composition and compressibility are constant.	Saturated Groundwater Flow (N23) Fluid Flow Due to Gas Production (W42)	R

References: Appendix MASS-2.0, General Assumptions in PA Models, and Appendix MASS-2.1, Darcy's Law Applied to Fluid Flow

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-2. General Modeling Assumption 7

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
7	BRAGFLO DRSPALL	The gas phase is assigned the density and viscosity properties of hydrogen (H_2).	Fluid Flow Due to Gas Production (W42)	R

Reference: Appendix MASS-2.2, Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties
*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-3. General Modeling Assumption 8

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
8	BRAGFLO	All liquid physical properties are assigned the properties of Salado brine.	Saturated Groundwater Flow (N23)	R

Reference: Appendix MASS-2.3, Salado Brine as Surrogate for Liquid Phase Physical Properties
*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-4. General Modeling Assumptions 9–13

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
9	BRAGFLO	The disposal system is represented by a two-dimensional, north-south, vertical cross-section.	Stratigraphy (N1) Physiography (N39)	R
10	BRAGFLO	Flow in the disposal system is radially convergent or divergent centered on the repository, shaft, and borehole for disturbed performance.	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24)	R
11	BRAGFLO	Variable dip in the Salado is approximated by a one-degree dip to the south.	Stratigraphy (N1)	R
12	BRAGFLO	Stratigraphic layers are parallel.	Stratigraphy (N1)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
13	BRAGFLO	The stratigraphy consists of units above the Dewey Lake, the Forty-niner, the Magenta, the Tamarisk, the Culebra, the Los Medaños, and the Salado Formations (comprising impure halite, marker bed [MB] 138, anhydrites A and B [lumped together], and MB 139). The dimensions of these units are constant. A Castile brine reservoir is included in the BRAGFLO grid in all scenarios.	Stratigraphy (N1)	R

References: CRA-2004 Chapter 6.0, Sections 6.4.2, Model Geometries, and 6.4.2.1, Disposal System Geometry, Appendix MASS-3.0, Model Geometries, and Appendix MASS-3.1, Disposal System Geometry for Flow and Transport

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-5. General Modeling Assumptions 14–16

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
14	MODFLOW6 SECOTP2D	The Culebra is represented by a two-dimensional, horizontal geometry for groundwater flow and radionuclide transport simulation.	Stratigraphy (N1)	R
15	MODFLOW6 PEST++	Transmissivity varies spatially. There is no vertical flow to or from the Culebra.	Groundwater Recharge (N54) Groundwater Discharge (N53)	R
16	SECOTP2D	The regional flow field provides boundary conditions for local transport calculations (see CRA-2004, Chapter 6.0, Section 6.4.10.2).	Advection (W90)	R

References: CRA-2004 Chapter 6.0, Section 6.4.2.2, Culebra Geometry, and Appendix TFIELD-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-6. General Modeling Assumptions 17–24

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
17	BRAGFLO	The repository comprises eight regions in addition to panel closure areas: the waste panel (WP), a north rest of repository (NROR), a south rest of repository (SROR), a west rest of repository (WROR), a south operations (SOPS) region, a west operations region (WOPS), a west drifts region (WD), and an experimental (EXP) region. A single shaft region is modeled, and a borehole region is included for a borehole that intersects the separate WP. The dimensions of these regions are constant.	Disposal Geometry (W1)	R-C
18	BRAGFLO	Although there will be no waste emplacement in Panel 9, waste is modeled in Panel 9 (see Appendix MASS-14.4).	Disposal Geometry (W1)	C
19	BRAGFLO	Long-term flow up plugged and abandoned boreholes modeled as if all intrusions occur into a down-dip (southern) panel.	Disposal Geometry (W1)	C
20	BRAGFLO	For each repository region, the model geometry preserves design volume.	Disposal Geometry (W1)	R
21	BRAGFLO	Pillars, individual drifts, and rooms are not modeled for long-term performance, and containers provide no barrier to fluid flow.	Disposal Geometry (W1)	C
22	BRAGFLO	Long-term flow is radial to and from the borehole that intersects the waste disposal panel during disturbed performance.	Waste-Induced Borehole Flow (H32)	R
23	BRAGFLO	Disturbed rock zone (DRZ) provides a pathway to MBs.	None	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
24	BRAGFLO	Grid dimensions for the intact and open panel closure areas are consistent with the run-of-mine panel closure system (ROMPCS) design. Material properties for intact panel closure areas are consistent with the ROMPCS panel closure design. In contrast, the material properties of open panel closure areas are identical to properties in the EXP, WD, SOPS, and WOPS regions. Ventilation bulkheads and concrete block walls are assumed to have no long-term impact to performance.	None	R

References: Appendix PA-4.2, Two-Phase Flow: BRAGFLO, Appendix MASS-3.1, Disposal System Geometry for Flow and Transport, and Appendix MASS-14.0, Intrusion Borehole

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-7. General Modeling Assumptions 25–28

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
25	Sierra_SM	The creep closure model simplifies the waste panel geometry to an infinite array of equally spaced parallel rooms, each of which is infinitely long. Variations in porosity across a panel are considered insignificant.	Salt Creep (W20) Changes in the Stress Field (W21) Excavation-Induced Changes in Stress (W19)	R
26	Sierra_SM	The amount of creep closure is a function of time, gas pressure, mechanical properties of the host rock, waste-matrix strength, and the lithostatic pressure distribution near the repository.	Salt Creep (W20) Changes in the Stress Field (W21) Consolidation of Waste (W32) Pressurization (W26)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
27	BRAGFLO	Porosity of waste areas (WP, SROR, NROR, and WROR) is a function of time and fluid pressure, which are correlated to time and gas pressure in the creep closure calculations.	Salt Creep (W20)	R
28	BRAGFLO	Porosity of the open panel closure, EXP, WD, SOPS, and WOPS areas is fixed at a value representative of consolidated material.	Salt Creep (W20)	R

Reference: Appendix PORSURF-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-8. General Modeling Assumptions 29–30

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
29	BRAGFLO	General Modeling Assumptions 1 to 8.	None	R
30	BRAGFLO	The waste disposal region is assigned a constant permeability representative of average consolidated waste without backfill.	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.2, Repository Fluid Flow, and MASS-5.0, Repository Fluid Flow

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-9. General Modeling Assumption 31

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
31	BRAGFLO	The EXP, WD, SOPS, and WOPS regions are assigned a constant permeability representative of unconsolidated material and a constant porosity representative of consolidated material. The open panel closure area between the WP and SROR regions is assigned the same properties as the EXP, WD, SOPS, and WOPS regions.	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24) Salt Creep (N20)	C

Reference: Appendix MASS-5.1, Flow Interactions with the Creep Closure Model

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-10. General Modeling Assumption 32

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
32	BRAGFLO	For iron corrosion and microbial degradation associated gas generation (and water production) calculations, the effects of wicking are accounted for by assuming that brine in the repository contacts waste to an extent greater than that calculated by the two-phase flow model.	Wicking (W41)	R

Reference: Appendix MASS-5.0, Repository Fluid Flow

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-11. General Modeling Assumptions 33–36

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
33	BRAGFLO	Gas generation occurs through the anoxic corrosion of steel containers and Fe and Fe-based alloys in the waste, resulting in the production of H_2. Lead corrosion does not contribute to gas generation (Appendix SCR-6.1.3.2.3). Gas generation is calculated using the average-stoichiometry model and is dependent on brine availability.	Container Material Inventory (W5) Waste Inventory (W2) Gases from Metal Corrosion (W49)	R-C
34	BRAGFLO	Gas generation occurs through the microbial consumption of cellulosics and, possibly, plastics and rubbers (CPR), giving mainly carbon dioxide (CO_2) and hydrogen sulfide (H_2S).	Waste Inventory (W2) Degradation of Organic Material (W44)	R
35	BRAGFLO	Radiolysis contributes to gas generation through the consumption of brine and the production of H_2. Radiolysis of CPR, oxic reactions, and other gas generation mechanisms are insignificant.	Waste Inventory (W2) Radiolysis of Brine (W52)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
36	BRAGFLO	The anoxic corrosion rate is dependent on fluid saturation. Anoxic corrosion of steel continues until all the zero-valent iron is consumed. Steel corrosion will not be passivated by microbially generated gases (CO_2 or H_2S). The water in brine is consumed by the corrosion reaction.	Brine Inflow (W40) Gases from Metal Corrosion (W49) Degradation of Organic Material (W44)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.3, Gas Generation, Appendix TRU WASTE-2026, Appendix MASS-6.0, Gas Generation, CRA-2019 Appendix MASS-6.1, Iron Surface Area, and Appendix GEOCHEM-3.2, Parameterization of the Chemical Conditions Process Model

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-12. General Modeling Assumptions 37–41

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
37	BRAGFLO	Laboratory-scale experimental measurements of gas generation rates at expected room temperatures are used to account for the effects of biofilms and chemical reactions.	Effects of Biofilms on Microbial Gas Generation (W48) Effects of Temperature on Microbial Gas Generation (W45) Chemical Effects of Corrosion (W51)	R
38	BRAGFLO	The rate of microbial gas production is dependent on the amount of fluid present.	Brine Inflow (W40) Degradation of Organic Material (W44) Waste Inventory (W2)	C

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
39	BRAGFLO	Microbial activity occurs in all the simulations. In 75% of the simulations, microbes may consume all of the cellulosics but none of the plastics and rubbers. In the remaining 25% of the simulations, microbes may consume all of the CPR materials.	Degradation of Organic Material (W44) Waste Inventory (W2)	C
40	BRAGFLO	Microbial production will continue until all biodegradable CPR materials are consumed if brine is present.	Brine Inflow (W40) Degradation of Organic Material (W44) Waste Inventory (W2)	C
41	BRAGFLO	The magnesium oxide (MgO) backfill will react with the CO_2 and remove it sufficiently from the gaseous phase such that its contribution to overall gas generation rates is negligible—the very low amount of CO_2 assumed to exist in the repository does not contribute to the amount of gas generated in the repository.	Waste Inventory (W2)	C

References: CRA-2004 Chapter 6.0, Section 6.4.3.3, Gas Generation, Appendix TRU WASTE-2026, Appendix MASS-6.0, Gas Generation, CRA-2019 Appendix MASS-6.1, Iron Surface Area, and Appendix GEOCHEM-3.2, Parameterization of the Chemical Conditions Process Model

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-13. General Modeling Assumptions 42–47

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
42	BRAGFLO	Alpha radiolysis of brine will result in the production of H_2 and oxygen such that one mole of gas (H_2) is produced for each net mole of water consumed (Day 2019).	Radiolysis of Brine (W52)	R
43	BRAGFLO	Gas generation due to alpha radiolysis of brine by radionuclides in solution and in wetted-solid form is assumed to contribute to repository pressure (Day 2019).	Radiolysis of Brine (W52)	R
44	BRAGFLO	Only a portion of the disintegration energy associated with wetted-solid alpha-emitting radionuclides in the inventory will contribute to radiolytic H_2 generation (Day 2019).	Radiolysis of Brine (W52)	R
45	BRAGFLO	The total radiolytic H_2 generation rate (and brine consumption rate) is due to contributions from one or more decaying radionuclides in the waste volume (Day 2019).	Radiolysis of Brine (W52)	R
46	BRAGFLO	Gas dissolution in brine is of negligible consequence.	Fluid Flow Due to Gas Production (W42)	C
47	BRAGFLO	The gaseous phase is assigned the properties of H_2 (General Assumption 7).	Fluid Flow Due to Gas Production (W42)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.3, Gas Generation, Appendix TRU WASTE-2026, Appendix MASS-6.0, Gas Generation, CRA-2019 Appendix MASS-6.1, Iron Surface Area, and Appendix GEOCHEM-3.2, Parameterization of the Chemical Conditions Process Model

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-14. General Modeling Assumptions 48–53

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
48	NUTS PANEL	Chemical conditions in the repository will be constant. Chemical equilibrium is assumed for all reactions that occur between brine in the repository, waste, and abundant minerals, with the exceptions of gas generation and actinide redox reactions. The uncertainty in redox reaction kinetics (i.e., equilibrium) is taken into account via the source term model where a range of redox conditions is considered across realizations.	Speciation (W56) Reduction-Oxidation Kinetics (W66)	R
49	NUTS PANEL	Brine and waste in the repository will contain a uniform mixture of dissolved and colloidal species. All actinides have instant access to all repository brine.	Heterogeneity of Waste Forms (W3) Speciation (W56)	C
50	NUTS PANEL	No microenvironments that influence the overall chemical environment will persist.	Speciation (W56)	R
51	NUTS PANEL	For the undisturbed performance and E2 scenarios, brine in the waste regions has the composition of Salado brine. For E1 and E1E2 (Appendix PA-2.3) scenarios, all brine in the waste regions has the composition of Castile brine.	Speciation (W56)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
52	NUTS PANEL	Chemical conditions in the waste panels will be reducing. However, a condition of redox disequilibrium will exist between the possible oxidation states of the actinide elements.	Reduction-Oxidation Kinetics (W66) Speciation (W56) Effects of Metal Corrosion (W64)	R
53	NUTS PANEL	The pH and CO_2 fugacity in the waste panels will be controlled by the formation of brucite ($Mg(OH)_2$), hydromagnesite ($Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$), calcite ($CaCO_3$), and cerrusite ($PbCO_3$). (A result of this assumption is low CO_2 fugacity and mildly basic conditions.)	Speciation (W56) Backfill Chemical Composition (W10)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.4, Chemical Conditions in the Repository, Appendix SOTERM-2.0, Ambient Geochemical Conditions, Repository Conditions, Emplacement Chemistry and Processes that Affect the WIPP Actinide Source Term, Appendix MASS-7.0, Chemical Conditions, Appendix GEOCHEM-3.0, Chemical Conditions, and Appendix: SOTERM-6.4, Redox and Oxidation State Distribution in the WIPP

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-15. General Modeling Assumptions 54–61

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
54	NUTS PANEL	Radionuclide dissolution to solubility/inventory limits is instantaneous.	Dissolution of Waste (W58)	C
55	NUTS PANEL	Six actinides (thorium [Th], uranium [U], neptunium [Np], plutonium [Pu], americium [Am], and curium [Cm]) are used in PANEL for calculations of radionuclide transport of	Waste Inventory (W2)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
		brine (up a borehole). Four actinides (Th, U, Pu, and Am) are explicitly considered in NUTS for calculations of radionuclide transport in brine (porous materials) (Kicker 2025).		
56	NUTS PANEL SECOTP2D	The reducing conditions in the repository will eliminate significant concentrations of Np(VI), Pu(V), Pu(VI), and Am(V) species. Am and Cm will exist predominantly in the III oxidation state, while Th will exist in the IV oxidation state. It is assumed that the solubilities and Culebra matrix partition coefficient (K_d) values of U, Np, and Pu will be dominated by one of the remaining oxidation states: U(IV) or U(VI), Np(IV) or Np(V), and Pu(III) or Pu(IV) (See Appendix PA-4.9).	Speciation (W56) Reduction-Oxidation Kinetics (W66)	R
57	NUTS PANEL	For a given oxidation state, the different actinides have similar solubilities.	Speciation (W56)	R-C

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
58	NUTS PANEL	For undisturbed performance and for all aspects of disturbed performance, except for cuttings and cavings releases (see General Modeling Assumption 136), radionuclides in the waste are distributed evenly throughout the disposal panel.	Waste Inventory (W2) Heterogeneity of Waste Forms (W3)	R
59	NUTS PANEL	Mobilization of actinides in the gas phase is negligible.	Dissolution of Waste (W58)	R
60	NUTS PANEL	The inventory limitation for actinide masses is based on the inventory available in five panels, because, due to the lack of an intact panel closure between the WP and SROR regions, an intrusion into the WP has the potential to provide brine for mobilization of actinides in both the WP and SROR regions, which correspond to a total of five panels. The inventory limitation applies globally for any panel. Even though panels in the NROR and WROR are separated by panel closures such that there is no communication expected, the assumption of solubility	Dissolution of Waste (W58)	C

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
		accounting for up to five panels of waste is used.		
61	NUTS PANEL	Actinide concentrations in the repository will be inventory limited when the mass of an actinide becomes depleted such that the predicted concentrations cannot be achieved.	Dissolution of Waste (W58)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.5, Dissolved Actinide Source Term, Appendix GEOCHEM-4.1.2, Use of the Pitzer Model, Appendix MASS-8.0, Dissolved Actinide Source Term, Appendix PA-4.4, Radionuclide Mobilization in the Repository: PANEL, and Appendix SOTERM-6.1, Overview of WIPP Approach to Calculate Mobile Actinide Concentrations

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-16. General Modeling Assumptions 62–65

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
62	NUTS PANEL	Four types of colloids constitute the source term for colloidal actinides: intrinsic, mineral fragment, microbial, and humic.	Colloid Formation and Stability (W79) Humic and Fulvic Acids (W70)	R
63	NUTS PANEL	Intrinsic colloids for all actinides are experimentally defined (Kaplan et al. 2025).	Colloid Formation and Stability (W79)	R
64	NUTS PANEL	Concentrations of intrinsic colloids and mineral-fragment colloids are modeled as constants derived from experimental data. For humic and microbial colloidal contributions, actinide concentrations are modeled as proportional to dissolved actinide concentrations.	Colloid Formation and Stability (W79)	R-C

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
65	NUTS PANEL	In calculating mobilized radionuclide concentrations, the maximum concentration of each actinide associated with each colloid type is constant.	Actinide Sorption (W61)	R

References: CRA-2004 Chapter 6.0, Section 6.4.3.6, Source Term for Colloidal Actinides, Appendix MASS-9.0, Colloidal Actinide Source Term, and Appendix SOTERM-3.5, Actinide Colloids

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-17. General Modeling Assumptions 66–70

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
66	BRAGFLO	General Assumptions 1 to 8.	None	R
67	BRAGFLO	The five shafts connecting the repository to the surface are represented by a single shaft with a cross-section and volume equal to the total volume of the five real shafts and separated from the waste by less than the distance of the nearest real shaft.	Disposal Geometry (W1)	R
68	BRAGFLO	The shaft seal system is represented by an upper and lower shaft region representing a composite of the actual materials in those regions.	Shaft Seal Geometry (W6) Shaft Seal Physical Properties (W7)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
69	BRAGFLO	The shaft is surrounded by a DRZ, which heals with time. The DRZ is represented through the composite permeabilities of the shaft system itself, rather than as a discrete zone. The effective permeabilities of shaft materials are adjusted at 200 years after closure to reflect consolidation and possible degradation. Permeabilities are constant for the shaft seal materials through the Rustler Formation.	Salt Creep (W20) Consolidation of Shaft Seals (W36) DRZ (W18) Microbial Growth on Concrete (W76) Chemical Degradation of Shaft Seals (W74) Mechanical Degradation of Shaft Seals (W37)	R
70	NUTS	Radionuclides are not retarded by the shaft seal materials.	Actinide Sorption (W61) Speciation (W56)	C

References: CRA-2004 Chapter 6.0, Section 6.4.4, Shafts and Shaft Seals, and Appendix MASS-10.0, Shafts and Shaft Seals

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-18. General Modeling Assumption 71

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
71	BRAGFLO	General Assumptions 1 to 8.	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.5, The Salado

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-19. General Modeling Assumption 72

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
72	BRAGFLO	Intact rock and hydrologic properties are constant.	Stratigraphy (N1)	R

References: CRA-2004 Chapter 6.0, Section 6.4.5.1, Impure Halite, and Appendix MASS-11.1, High Threshold Pressure for Halite-Rich Salado Rock Unit

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-20. General Modeling Assumptions 73–74

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
73	BRAGFLO	Interbeds have a fracture-initiation pressure above which local fracturing and changes in porosity and permeability occur in response to changes in pore pressure. A power function relates the permeability increase to the porosity increase. A pressure is specified above which porosity and permeability do not change.	Disruption Due to Gas Effects (W25)	R
74	BRAGFLO	Interbeds have identical physical properties; they differ only in position, thickness, and some fracture parameters.	Saturated Groundwater Flow (N23)	R

References: CRA-2004 Chapter 6.0, Section 6.4.5.2, Salado Interbeds, and Appendix MASS-11.2, The Fracture Model

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-21. General Modeling Assumption 75

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
75	BRAGFLO	The permeability of the DRZ is sampled with the low value similar to intact halite and the high value representing a fractured material. The DRZ porosity is equal to the porosity of Salado halite plus 0.29%.	Disturbed Rock Zone (DRZ) (W18) Roof Falls (W22) Gas Explosions (W27) Seismic Activity (N12) Underground Boreholes (W39)	R-C

References: CRA-2004 Chapter 6.0, Section 6.4.5.3, Disturbed Rock Zone, and Appendix MASS-11.3, Flow in the DRZ

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-22. General Modeling Assumptions 76–79

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
76	NUTS	Dissolved actinides and colloidal actinides are transported by advection in the Salado. Diffusion and dispersion are assumed negligible.	Advection (W90) Diffusion (W91) Matrix Diffusion (W92)	R
77	NUTS	Sorption of actinides in the anhydrite interbeds, colloid retardation, colloid transport at higher than average velocities, coprecipitation of minerals containing actinides, channeled flow, and viscous fingering are not modeled.	Actinide Sorption (W61) Colloid Transport (W78) Colloid Filtration (W80) Colloid Sorption (W81) Fluid Flow Due to Gas Production (W42) Fracture Flow (N25)	R-C

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
78	NUTS	Radionuclides having similar decay and transport properties have been grouped together for transport calculations (Kicker 2025). See also assumptions for dissolved actinide source term.	Radionuclide Decay and Ingrowth (W12)	R
79	NUTS	Sorption of actinides in the borehole is not modeled.	Actinide Sorption (W61)	C

References: CRA-2004 Chapter 6.0, Section 6.4.5.4, Actinide Transport in the Salado, and Appendix MASS-11.4, Actinide Transport in the Salado

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-23. General Modeling Assumption 80

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
80	SECOTP2D	Above the Salado, lateral actinide transport to the accessible environment can occur only through the Culebra.	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24) Solute Transport (W77)	R

References: CRA-2004 Chapter 6.0, Section 6.4.6, Units Above the Salado, and Appendix MASS-12.0, Geologic Units above the Salado

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-24. General Modeling Assumption 81

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
81	MODFLOW6 BRAGFLO	The Los Medaños member of the Rustler Formation is assumed to be impermeable.	Saturated Groundwater Flow (N23)	C

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.1, Los Medaños

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-25. General Modeling Assumptions 82–88

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
82	MODFLOW6 SECOTP2D	General Assumptions 1 and 6.	None	R
83	MODFLOW6	For fluid flow, the Culebra is modeled as a uniform (single-porosity) porous medium.	Saturated Groundwater Flow (N23)	R
84	MODFLOW6	The Culebra flow field is determined from the observed hydraulic conditions and estimates of the effects of climate change and potash mining outside the controlled area and does not change with time unless mining is predicted to occur in the disposal system in the future.	Saturated Groundwater Flow (N23) Climate Change (N61) Precipitation (e.g., Rainfall) (N59) Temperature (N60) Changes in Groundwater Flow Due to Mining (H37)	R
85	BRAGFLO	The Culebra is assigned a single permeability to calculate brine flow into the unit from an intrusion borehole.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
86	MODFLOW6	Gas flow in the Culebra is not modeled. Gas from the repository does not affect fluid flow in the Culebra.	Saturated Groundwater Flow (N23) Fluid Flow Due to Gas Production (W42)	R
87	BRAGFLO MODFLOW6 SECOTP2D	Different thicknesses of the Culebra are assumed for BRAGFLO, MODFLOW6, and SECOTP2D calculations, although the transmissivities are consistent.	Effects of Preferential Pathways (N27)	R
88	PEST++	Uncertainty in the spatial variability of the Culebra transmissivity is accounted for by statistically generating 100 transmissivity fields (T-fields) for PA.	Saturated Groundwater Flow (N23) Fracture Flow (N25) Shallow Dissolution (N16)	R

References: CRA-2004 Chapter 6.0, Section 6.4.6.2, The Culebra, Appendix MASS-13.0, Culebra, CRA-2014 Appendix TFIELD, Appendix MASS-15.0, Climate Change, and Appendix TFIELD-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-26. General Modeling Assumption 89

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
89	MODFLOW6 BRAGFLO	Potentiometric heads are set on the edges of the regional grid to represent flow in a portion of a much larger hydrologic system.	Groundwater Recharge (N54) Groundwater Discharge (N53) Changes in Groundwater Recharge and Discharge (N56) Infiltration (N55)	R

References: CRA-2004 Chapter 6.0, Section 6.4.6.2, The Culebra, Appendix MASS-13.0, Culebra, CRA-2014 Appendix TFIELD, Appendix MASS-15.0, Climate Change, and Appendix TFIELD-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-27. General Modeling Assumptions 90–94

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
90	SECOTP2D	Dissolved actinides are transported by advection in high-permeability features and by diffusion in low-permeability features.	Solute Transport (W77) Advection (W90) Diffusion (W91) Matrix Diffusion (W92)	R
91	SECOTP2D	Sorption occurs on dolomite in the matrix. Sorption on clays present in the Culebra is not modeled.	Actinide Sorption (W61) Changes in Sorptive Surfaces (W63)	C
92	SECOTP2D	Sorption is represented using a linear isotherm model.	Actinide Sorption (W61) Kinetics of Sorption (W62)	R
93	SECOTP2D	The possible effects on sorption of the injection of brines from the Castile and Salado into the Culebra are accounted for in the distribution of actinide K_d values.	Actinide Sorption (W61) Groundwater Geochemistry (N33) Changes in Groundwater Eh (N36) Changes in Groundwater pH (N37) Natural Borehole Fluid Flow (H31)	R
94	SECOTP2D	Hydraulically significant fractures are assumed to be present everywhere in the Culebra.	Advection (W90)	C

References: CRA-2004 Chapter 6.0, Section 6.4.6.2.1, Transport of Dissolved Actinides in the Culebra, and Appendix MASS-13.2, Dissolved Actinide Transport in the Culebra

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-28. General Modeling Assumptions 95–97

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
95	SECOTP2D	Actinide humic colloids are chemically retarded identically to dissolved actinides and are treated as dissolved actinides.	Advection (W90) Diffusion (W91) Colloid Transport (W78) Microbial Transport (W87)	R
96	SECOTP2D	The concentration of intrinsic colloids is sufficiently low to justify elimination from PA transport calculations in the Culebra.	None	R
97	SECOTP2D	Microbial colloids and mineral fragments are too large to undergo matrix diffusion. Filtration of these colloids, which is modeled using an exponential decay approach, occurs in high-permeability features. The effectiveness of attenuation is such that associated actinides are assumed to be retained within the disposal system and are not transported.	Microbial Transport (W87) Colloid Sorption (W81)	R

References: CRA-2004 Chapter 6.0, Section 6.4.6.2.2, Transport of Colloidal Actinides in the Culebra, and Appendix MASS-13.3, Colloidal Actinide Transport in the Culebra

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-29. General Modeling Assumption 98

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
98	MODFLOW6	The effect of potash mining is to increase the hydraulic conductivity in the Culebra by a factor between 1 and 1,000.	Conventional Underground Potash Mining (H13) Changes in Groundwater Flow Due to Mining (H37)	Reg.

References: CRA-2004 Chapter 6.0, Section 6.4.6.2.3, Subsidence Due to Potash Mining, and Appendix MASS-13.4 Subsidence Caused by Potash Mining in the Culebra

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-30. General Modeling Assumption 99

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
99	MODFLOW6 BRAGFLO	The Tamarisk is assumed to be impermeable.	Saturated Groundwater Flow (N23)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.3, The Tamarisk

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-31. General Modeling Assumptions 100–102

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
100	BRAGFLO	General Assumptions 1 to 8.	None	R
101	BRAGFLO	The Magenta permeability is set to the lowest value measured near the center of the WIPP site. This increases the flow into the Culebra.	Saturated Groundwater Flow (N23)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
102	NUTS	No radionuclides entering the Magenta will reach the accessible environment. However, the volumes of brine and actinides entering and stored in the Magenta are modeled.	Solute Transport (W77)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.4, The Magenta

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-32. General Modeling Assumption 103

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
103	BRAGFLO	The Forty-niner is assumed to be impermeable.	Saturated Groundwater Flow (N23)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.5, The Forty-niner

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-33. General Modeling Assumptions 104–105

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
104	BRAGFLO	General Assumptions 1 to 8.	None	R
105	NUTS	The sorptive capacity of the Dewey Lake is sufficiently large to prevent any release over 10,000 years.	Saturated Groundwater Flow (N23) Actinide Sorption (W61)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.6, Dewey Lake

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-34. General Modeling Assumptions 106–108

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
106	BRAGFLO	General Assumptions 1 to 8.	None	R
107	BRAGFLO	The units above the Dewey Lake are a single hydrostratigraphic unit.	Stratigraphy (N1)	R
108	BRAGFLO	The units are thin and predominantly unsaturated.	Unsaturated Groundwater Flow (N24) Saturated Groundwater Flow (N23)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.6.7, Supra-Dewey Lake Units

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-35. General Modeling Assumption 109

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
109	CUTTINGS_S BRAGFLO DRSPALL	Any actinides that enter the borehole during drilling are assumed to reach the surface.	None	C

References: CRA-2004 Chapter 6.0, Section 6.4.7, The Intrusion Borehole, CRA-2004 Chapter 6.0, Section 6.4.7.1, Releases during Drilling, and Appendix MASS-14.0, Intrusion Borehole

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-36. General Modeling Assumptions 110–115

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
110	BRAGFLO PANEL CUTTINGS_S DRSPALL CCDFGF	Future drilling practices will be the same as they are at present.	Oil and Gas Exploration (H1) Potash Exploration (H2) Oil and Gas Exploitation (H4) Other Resources (H8) Enhanced Oil and Gas Recovery (H9)	Reg.
111	CUTTINGS_S DRSPALL	Releases of particulate waste material are modeled (i.e., cuttings, cavings, and spallings). Releases are corrected for radioactive decay until the time of intrusion.	Drilling Fluid Flow (H21) Suspension of Particles (W82) Cuttings (W84) Cavings (W85) Spallings (W86)	R
112	CUTTINGS_S	Degraded waste properties are based on surrogate materials.	Cavings (W85)	C
113	DRSPALL	A hemispherical geometry with one-dimensional spherical symmetry defines the flow field and cavity in the waste.	Spallings (W86)	C
114	DRSPALL	Tensile strength based on completely degraded waste surrogates represents extreme, low-end tensile strengths because it does not account for several strengthening mechanisms.	Spallings (W86)	C
115	DRSPALL	Shape factor is 0.1, corresponding to particles that are easier to fluidize and entrain in the flow.	Spallings (W86)	C

Reference: Appendix MASS-14.1, Cuttings, Cavings, and Spall Releases during Drilling

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-37. General Modeling Assumptions 116–118

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
116	BRAGFLO PANEL	Brine containing actinides may flow to the surface during drilling. Direct brine release will have negligible effect on the long-term pressure and saturation in the WP region.	Blowouts (H23)	C
117	BRAGFLO	A two-dimensional grid (one-degree dip) with representative areas for each of the waste disposal regions (WP, SROR, NROR, WROR) is used for DBR calculations.	Blowouts (H23)	R
118	BRAGFLO CCDFGF	Calculation of DBR from several different locations provides reference results for the variation in release associated with the intrusion location, the degree of panel closures separating it from the location of a previous intrusion, and whether two panels are in different halves of the repository.	Blowouts (H23)	R

References: CRA-2004 Chapter 6.0, Section 6.4.7.1.1, Direct Brine Release During Drilling, and Appendix MASS-14.2, Direct Brine Releases During Drilling

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-38. General Modeling Assumption 119

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption *
119	BRAGFLO CCDFGF	Plugging and abandonment of future boreholes are assumed to be consistent with current practices in the Delaware Basin.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	Reg.

References: CRA-2004 Chapter 6.0, Section 6.4.7.2, Long-Term Releases Following Drilling, and Appendix MASS-14.3, Long-Term Properties of the Abandoned Intrusion Borehole

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-39. General Modeling Assumption 120

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
120	CCDFGF	A continuous concrete plug is assumed to exist throughout the Salado and Castile. Long-term releases through a continuous plug are analogous to releases through a sealed shaft.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.7.2.1, Continuous Concrete Plug through the Salado and Castile (Plug type VI in U.S. DOE 2025)

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-40. General Modeling Assumptions 121–122

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption *
121	BRAGFLO	A lower plug is located between the Castile brine reservoir and underlying formations (as represented by a no flow boundary condition). A second plug is located immediately above the Salado. The brine reservoir and WP region are in direct communication through an open cased hole.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	Reg.-R
122	BRAGFLO	The casing and upper concrete plug are assumed to fail after 200 years, and the borehole is assumed to be filled with silty-sand-like material. At 1,200 years after abandonment, the permeability of the borehole below the WP region is decreased by one order of magnitude as a result of salt creep.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.7.2.2, The Two-Plug Configuration (Plug types I, III, and V in U.S. DOE 2025)

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-41. General Modeling Assumption 123

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
123	CCDFGF	In addition to the two-plug configuration, a third plug is placed within the Castile above the brine reservoir. The third plug is assumed not to fail over the regulatory time period.	Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.7.2.3, The Three-Plug Configuration (Plug types II and IV in U.S. DOE 2025)

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-42. General Modeling Assumption 124

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
124	BRAGFLO	Brine occurrences in the Castile are bounded systems. Brine reservoirs under the waste panels are assumed to have limited extent and interconnectivity, with effective radii on the order of several hundred meters (m).	Brine Reservoirs (N2)	R

References: CRA-2004 Chapter 6.0, Section 6.4.8, Castile Brine Reservoir, and Appendix MASS-16.0, Castile Brine Reservoir

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-43. General Modeling Assumption 125

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
125	SECOTP2D	Climate-related factors are treated through recharge. A parameter called the Climate Index is used to scale the Culebra flux field.	Climate Change (N61) Temperature (N60) Precipitation (e.g., Rainfall) (N59)	R

References: CRA-2004 Chapter 6.0, Section 6.4.9, Climate Change, and Appendix MASS-15.0, Climate Change
*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-44. General Modeling Assumptions 126–128

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
126	BRAGFLO	There are no gradients beyond the gravity-induced one-degree dip (southward) for flow in the far-field of the Salado, and pressures are above hydrostatic but below lithostatic. Excavation and waste emplacement result in partial drainage of the DRZ.	Saturated Groundwater Flow (N23) Brine Inflow (W40)	R
127	BRAGFLO	An initial water-table surface is set in the Dewey Lake at an elevation of 980 m (3,215 foot [ft]) above mean sea level. The initial pressures in the Salado are extrapolated from a sampled pressure in MB 139 at the shaft and are in hydrostatic equilibrium. The excavated region is assigned an initial pressure greater than one atmosphere to account for the incremental pressure generated by faster initial microbial gas	Saturated Groundwater Flow (N23)	R

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
		generation rates observed during laboratory experiments. The waste area pressure at the time of closure is dependent on the initial CPR inventory (King 2021a). The liquid saturation of the waste-disposal region is consistent with the liquid saturation of emplaced waste. Other excavated regions are assigned zero liquid saturation, except the shaft, which is fully saturated.		
128	NUTS	Molecular transport boundary conditions are no diffusion or dispersion in the normal direction across far-field boundaries. Initial actinide concentrations are zero everywhere, except in the waste.	Radionuclide Decay and Ingrowth (W12) Solute Transport (W77)	R

References: CRA-2004 Chapter 6.0, Section 6.4.10, Initial and Boundary Conditions for Disposal System Modeling, CRA-2004 Chapter 6.0, Section 6.4.10.1, Disposal System Flow and Transport Modeling (BRAGFLO and NUTS), and Appendix PA-4.2, Two-Phase Flow

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-45. General Modeling Assumptions 129–130

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
129	MODFLOW6	Constant head and no-flow boundary conditions are set on the far-field boundaries of the flow model.	Saturated Groundwater Flow (N23)	R
130	MODFLOW6	Initial actinide concentrations in the Culebra are zero.	Solute Transport (W77)	R

References: CRA-2004 Chapter 6.0, Section 6.4.10.2, Culebra Flow and Transport Modeling MODFLOW-2000, SECOTP2D), and Appendix TFIELD-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-46. General Modeling Assumption 131

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
131	NUTS PANEL BRAGFLO (DBR) CUTTINGS_S	Initial and boundary conditions are interpolated from previously executed BRAGFLO calculations.	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.10.3, Initial and Boundary Conditions for Other Computational Models

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-47. General Modeling Assumption 132

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
132	CCDFGF	Each 10,000-year future (random sequence of future events) is generated by randomly and repeatedly sampling (1) the time between drilling events, (2) the location of drilling events, (3) the activity level of the waste penetrated by each drilling intrusion, (4) the plug configuration of the borehole, (5) the penetration of a Castile brine reservoir, and (6) the occurrence of mining in the disposal system.	Oil and Gas Exploration (H1) Potash Exploration (H2) Oil and Gas Exploitation (H4) Other Resources (H8) Enhanced Oil and Gas Recovery (H9) Natural Borehole Fluid Flow (H31) Waste-Induced Borehole Flow (H32)	Reg.-R

References: CRA-2004 Chapter 6.0, Section 6.4.12, Sequences of Future Events, and Appendix MASS-18.0, Evaluation of Waste Structural Impacts, Emplacement, and Homogeneity

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-48. General Modeling Assumption 133

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
133	CCDFGF	Active institutional controls are effective for 100 years after closure and completely eliminate the possibility of disruptive human activities (e.g., drilling and mining). No credit is taken for passive institutional controls during this time.	None	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.1, Active and Passive Institutional Controls in Performance Assessment

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-49. General Modeling Assumption 134

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
134	CCDFGF	Drilling may occur beginning 100 years after closure according to a Poisson process.	Loss of Records (H57) Oil and Gas Exploration (H1) Potash Exploration (H2) Oil and Gas Exploitation (H4) Other Resources (H8)	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.2, Number and Time of Drilling Intrusions

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-50. General Modeling Assumption 135

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
135	CCDFGF	The waste disposal region is represented by 12 regions (corresponding to 12 panels), each with a probability of being intersected proportional to its assumed footprint. A single borehole can penetrate only one region. The region/panel neighbor relationship for two panels is defined as "connected" for panels with zero intact panel closures between them, "adjacent" if both panels are in the same half of the repository but are separated by one or more intact panel closures between them, and "non-adjacent" for panels in different halves of the repository.	Disposal Geometry (W1)	R

References: CRA-2004 Chapter 6.0, Section 6.4.12.3, Location of Intrusion Boreholes, and Appendix MASS-14.2, Direct Brine Releases during Drilling

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-51. General Modeling Assumption 136

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
136	CCDFGF	Four hundred eighty-five (485) waste streams are identified as contact-handled transuranic (CH-TRU) and 105 waste streams are identified as remote-handled transuranic (RH-TRU) (Kicker 2025). For each of the CH and RH cases, cuttings and cavings activities are derived from individual waste streams, with a probability of intersection based on the relative waste stream volume.[3] Spallings concentrations are equal to the average CH-TRU concentration.	Heterogeneity of Waste Forms (W3)	R

References: CRA-2004 Direct Brine Releases during Drilling 6.4.12.4, Activity of the Intersected Waste, Appendix TRU WASTE-2004, and Appendix MASS-14.1.4, Calculation of Cuttings, Cavings, and Spallings Releases

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

[3] Unlike in previous PAs, the CRA-2026 PA assumes a waste inventory less than the Land Withdrawal Act (LWA) maximum waste volume for both CH-TRU and RH-TRU wastes (Ward 2025). Waste stream intersection probabilities are based on the ratio of volume of the waste stream relative to the total waste volume, calculated separately for CH-TRU and RH-TRU waste streams.

Table MASS-52. General Modeling Assumption 137

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
137	CUTTINGS_S	The diameter of the intrusion borehole is constant at 12.25 inches (in.) (31.12 centimeters [cm]).	None	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.5, Diameter of the Intrusion Borehole

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-53. General Modeling Assumption 138

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
138	CCDFGF	The probability that a deep borehole intersects the single brine reservoir below the waste panels is sampled from a defined distribution.	Brine Reservoirs (N2)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.6, Probability of Intersecting a Brine Reservoir

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-54. General Modeling Assumption 139

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
139	CCDFGF	The two-plug configuration has a probability of 0.464. The three-plug configuration has a probability of 0.177. The continuous concrete plug has a probability of 0.359 (Feng and Kicker 2025).	None	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.7, Plug Configuration in the Abandoned Intrusion Borehole

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-55. General Modeling Assumption 140

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
140	CCDFGF	Mining into the disposal system occurs a maximum of once in 10,000 years (a 10^{-4} probability per year).	None	Reg.-R

Reference: CRA-2004 Chapter 6.0, Section 6.4.12.8, Probability of Mining Occurring in the Land Withdrawal Area

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-56. General Modeling Assumptions 141–142

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
141	CCDFGF	Deterministic calculations from BRAGFLO, NUTS, MODFLOW6, SECOTP2D, CUTTINGS_S, DRSPALL, and PANEL are used to generate reference conditions that are used to estimate the consequences associated with random sequences of future events. These are, in turn, used to develop CCDFs.	None	R
142	CCDFGF	Ten thousand random sequences of future events are generated for each CCDF plotted.	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13, Construction of a Single Complementary Cumulative Distribution Function (CCDF)

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-57. General Modeling Assumption 143

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
143	CCDFGF	A BRAGFLO and NUTS calculation with undisturbed conditions is sufficient for estimating the consequences of the undisturbed performance scenario.	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.1, Constructing Consequences of the Undisturbed Performance Scenario

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-58. General Modeling Assumption 144

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
144	CCDFGF	Consequences for random sequences of future events are constructed by scaling the consequences associated with deterministic calculations (reference conditions) to other times, generally by interpolation, but sometimes by assuming either similarity or no consequence.	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.2, Scaling Methodology for Disturbed Performance Scenarios

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-59. General Modeling Assumption 145

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
145	CCDFGF NUTS	Reference conditions are calculated or estimated for intrusions at 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years. For multiple E1 intrusions into the same panel, the additional source term to the Culebra for the second and subsequent intrusions is assumed to be negligible.	Waste-Induced Borehole Flow (H32)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.3, Estimating Long-Term Releases from the E1 Scenario
*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-60. General Modeling Assumption 146

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
146	CCDFGF NUTS	The methodology is similar to the methodology for the E1 scenario. For multiple E2 intrusions into the same panel, the additional source term to the Culebra for the second and subsequent intrusions is assumed to be negligible.	Waste-Induced Borehole Flow (H32) Waste Inventory (W2)	R

*Reference: CRA-2004 Chapter 6.0, Section 6.4.13.4, Estimating Long-Term Releases from the E2 Scenario
*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-61. General Modeling Assumptions 147–149

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
147	CCDFGF PANEL	The concentration of actinides in liquid moving up the borehole assumes homogeneous mixing within the panel.	Waste-Induced Borehole Flow (H32)	C
148	PANEL	Any actinides that enter the borehole for long-term flow calculations reach the Culebra.	Waste-Induced Borehole Flow (H32)	C
149	CCDFGF PANEL	Reference conditions are calculated or estimated for intrusion at 100, 350, 1,000, 2,000, 4,000, 6,000, and 9,000 years.	Oil and Gas Exploration (H1)	—

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.5, Estimating Long-Term Releases from the E1E2 Scenario

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-62. General Modeling Assumption 150

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
150	CCDFGF PANEL	The panels are assumed not to be interconnected for long-term brine flow, although due to the open panel closure area modeled between the SROR and WP, some communication among panels effectively exists (Zeitler et al. 2017).	Saturated Groundwater Flow (N23) Unsaturated Groundwater Flow (N24)	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.6, Multiple Scenario Occurrences

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-63. General Modeling Assumptions 151–152

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
151	CCDFGF PANEL NUTS	Repository conditions will be dominated by Castile brine if any borehole connects to a brine reservoir.	Brine Reservoirs (N2) Natural Borehole Fluid Flow (H31)	R
152	CUTTINGS_S PANEL CCDFGF	Depletion of actinides in parts of the repository penetrated by boreholes is not accounted for in calculating the releases from single and subsequent intrusions at such locations.	Waste-Induced Borehole Flow (H32) Waste Inventory (W2)	C

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.7, Estimating Releases During Drilling for All Scenarios

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-64. General Modeling Assumption 153

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
153	SECOTP2D CCDFGF	Multiple potential release points from the repository into the Culebra are considered.	None	R

References: Appendix MASS-14.4, Multiple Release Points into Culebra, and Appendix PA-2026

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

Table MASS-65. General Modeling Assumptions 154–155

Assumption Number	Code	Modeling Assumption	Related FEP in Appendix SCR-2026	Basis(es) of Assumption*
154	CCDFGF	Releases from intrusions at random times in the future are scaled from releases calculated at 100 years with a unit source of radionuclides in the Culebra.	None	R
155	CCDFGF	Actinides in transit in the Culebra when mining occurs are transported in the flow field used for the undisturbed case. Actinides introduced subsequent to mining are transported in the flow field used for the disturbed case (i.e., the mined case).	None	R

Reference: CRA-2004 Chapter 6.0, Section 6.4.13.8, Estimating Releases in the Culebra and the Impact of the Mining Scenario

*Notes: R = Reasonable; C = Conservative; Reg. = Based on regulatory criteria or guidance; Assumptions with dual designations (e.g., R-C) have aspects of both.

MASS-2.1 Darcy's Law Applied to Fluid Flow

Darcy's Law is a mathematical expression that relates fluid flux to the gradient of hydraulic potential in a porous medium. In WIPP PA, flow in the disposal system and Salado is modeled as two-phase (brine + gas) Darcy flow—each phase's permeability scaled by saturation-dependent relative permeability and linked by capillary-pressure functions (see Appendix PA-4.2). Flow in the Culebra is modeled as single-phase (brine) Darcy flow (see Appendix PA-4.9). These assumptions have not changed since the CCA. Darcy's Law is not applied for flow up a borehole being drilled (see Appendix MASS-14.2; the CRA-2004, Chapter 6.0, Section 6.4.7.1.1; and Appendix PA-4.8 for more discussion on this topic).

Darcy's Law generally applies to flow models for which certain conditions are satisfied: (1) the flow occurs in a porous medium with interconnected porosity, (2) flow velocities are low enough that viscous forces dominate inertial forces, and (3) a threshold hydraulic gradient is exceeded. In the CCA, Appendix MASS, these conditions were shown to be valid for WIPP PA.

Darcy's Law assumes laminar flow; that is, there is no motion of the fluid at the fluid/solid interface, and velocity increases with distance from the fluid/solid interface. For liquids, it is reasonable to assume laminar flow under most conditions, including those found in and surrounding the WIPP repository. For gases at low pressure, however, gas molecules near the solid interface may not have intimate contact with the solid and may have finite, non-zero velocity. This effect, which results in additional flux of gas above that predicted by application of Darcy's Law, is known as the slip phenomenon, or Klinkenberg effect (Bear 1972, p. 128). A correction to Darcy's Law for the Klinkenberg effect is incorporated into the model for Salado flow[4] (see Appendix PA-4.2).

Darcy flow for one and two phases implies that values for the principal fluid and rock parameters must be specified. Fluid properties in the Darcy flow model used for WIPP PA are density, viscosity, and compressibility, while rock properties are porosity, permeability, and compressibility (pore or bulk). In the model for Salado flow, other parameters are required to describe the interactions between the gas and brine phases present in the model because those phases can occupy the same pore space. In the WIPP application of Darcy flow models, the compressibility of both the liquid and the rock is related to porosity through pressure dependence. Fluid density, viscosity, and compressibility are functions of fluid composition, pressure, and temperature. In the model for Salado flow, fluid density and compressibility are both pressure dependent, but fluid viscosity is constant. Fluid composition for modeling flow and transport is assumed to be constant.

MASS-2.2 Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties

The use of H_2gas as a surrogate for waste-generated gas in WIPP PA has not changed since the CCA. Hydrogen gas is produced by the anoxic corrosion of steel and by the radiolysis of brine in the repository. As in the CCA, the gas phase in the model for Salado flow is assigned the properties of H_2 because H_2 will, under most conditions considered in WIPP, be the dominant component of the gas phase. The model for spallings also assigns the physical properties of H_2 to the gas phase.

Other gases may be produced by processes occurring in the repository. If microbial degradation occurs, significant amounts of CO_2 and H_2S will be generated from the microbial degradation of cellulosics and, possibly, plastics and rubbers in the waste. The CO_2 produced, however, will react with the MgO engineered barrier and cementitious materials to form $Mg(OH)_2$, $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$, and $CaCO_3$. These reactions reduce the CO_2 fugacity in the repository. The H_2S generated by microbial degradation is assumed to persist and is treated as H_2 in PA calculations. Although other gases may exist in the disposal system, Salado flow calculations assume they are insignificant and not included in the model. The effect of assuming flow of

[4] Note that the terms "model for Salado flow" and "Salado flow model" are used interchangeably in this document. Both terms refer to the flow of brine and gas in all regions in and around the repository. The terms do not refer to the movement of salt in the Salado Formation.

pure H_2 instead of a mixture of gases (including H_2, CO_2, and H_2S) can be shown to be minor relative to the permeability variations in the surrounding formations.

With the average stoichiometry gas generation model, the total number of moles of gas generated will be the same whether the gas is H_2 or a mixture of several gases. This is because the generation of other gases is accounted for by specifying the stoichiometric factor for microbial degradation of cellulose (see Appendix GEOCHEM-2.4). Therefore, the pressure buildup in the repository can be calculated by considering only the moles of gas generated, because the expected gases behave like an ideal gas, even at lithostatic pressures.

The effect of assuming pure H_2 instead of a mixture of H_2, CO_2, and H_2S, on flow behavior, and its resulting impact on the WIPP repository pressure, is described in detail in CRA-2014 Appendix MASS-3.2.

MASS-2.3 Salado Brine as Surrogate for Liquid-Phase Physical Properties

The use of Salado brine as a surrogate for liquid phases in WIPP PA has not changed since the CCA. The model for flow in the Salado uses Salado Formation brine properties as the physical properties for all liquids, namely, density, viscosity, and compressibility. However, liquid in the modeled region may consist of (1) brine originally in the Salado, (2) liquid introduced in the excavation during construction, maintenance, and ventilation during the operational phase, (3) a very small amount of liquid introduced as a component of the waste, (4) liquid from overlying units, and (5) liquid from the Castile brine reservoir. However, for Salado flow modeling, it is assumed that the properties of all of these liquids are similar enough to Salado brine properties that the effect of any variation in properties due to mixing is negligible. Justification for this assumption is presented in the CCA Appendix MASS.3.3.

The variations in composition and chemical properties of brine are accounted for as discussed in Appendices SOTERM-3.2 and GEOCHEM-3.1.

MASS-3.0 MODEL GEOMETRIES

This section presents supplementary information on the disposal system geometry and includes a discussion of the representation of intact and open panel closure areas in that discussion. The principal process considered in defining the repository geometry is fluid flow. The model geometries implemented in WIPP PA have changed since the CRA-2019 PA, as described below. The most substantial changes are due to the consideration of two additional panels (Panels 11 and 12). The approach to representing additional panels that result in a waste panel layout that is no longer symmetric around a center line was approved by the CCMPR panel (Falta et al. 2021).

MASS-3.1 Disposal System Geometry for Flow and Transport

A vertical cross-section, through the repository on a north-south axis, is used to represent the disposal system in the models for long-term fluid flow and transport within the repository, in the Salado, and between a borehole and overlying units (see also Appendix PA-4.2.1).

Prior to the CRA-2026 PA, the 10-panel repository was symmetric around a center line on a north-south axis. For the CRA-2026 PA, the inclusion of replacement Panels 11 and 12 to the west of the centerline results in an asymmetric waste panel layout. The physical layout was represented by "unbending" the physical shape, placing a volume equivalent to Panels 11 and 12 along the center line. The key aspects preserved by this simplified representation include the total volumes of the additional panels and access drifts (Day 2025), the hydraulic connections between these volumes and the adjacent DRZ, Salado, and Salado interbeds, and the presence of panel closures separating each panel from the access drifts. This approach was first implemented in the 19-panel APPA analysis and found to be adequate by the APPA CCMPR panel (Falta et al. 2021). The 12-panel repository in the CRA-2026 PA comprises a subset of the 19 waste panels. Features and processes that influence flow and transport are the same in both the 12-panel and 19-panel repositories. Given the similarity between the 12-panel repository and the repository represented in the APPA, the conceptual models approved by the APPA CCMPR are adequate and reasonable for the 12-panel repository represented in the CRA-2026 PA.

The dimension of the repository geometry in the direction perpendicular to the cross-sectional plane varies to represent the spatial effects of repository processes. The use of a two-dimensional geometry to represent three-dimensional flow in the Salado assumes that brine and gas flow will converge upon and diverge from the repository horizon. This assumption does not change because of the approach taken to represent replacement Panels 11 and 12 to replace lost disposal capacity in Panels 1, 7, and 9 (i.e., replacement panels). Above and below the repository, it is assumed that any flow between the borehole or shaft (see CRA-2004, Chapter 6.0, Section 6.4.3) and surrounding materials will converge or diverge. Grid flaring is used in the disposal system geometry used for Salado flow modeling, and flows are represented as divergent and convergent from the flaring center (see CRA-2014 Appendix MASS-4.1.1.4). The impact of flaring in a two-dimensional grid has been compared to a model that does not assume convergent and divergent flow (see Appendix PA-2004, Attachment MASS, Section 4.1 for additional information). It has also been successfully compared to a fully three-dimensional repository representation (Falta et al. 2021).

MASS-3.2 Geometry for Flow During a Drilling Intrusion

For modeling brine flow from the intruded panel to the borehole during drilling, the DBR model uses a two-dimensional, horizontal representation of the repository waste area. The consideration of replacement panels resulted in changes to the horizontal representation of the repository waste area (see Appendix MASS-14.2).

MASS-3.3 Geometry for Flow and Transport in the Culebra

The geometry used to model brine flow in the Culebra flow model is a two-dimensional, horizontal representation of a 30 km × 30 km area around the WIPP site (see Bowman et al. 2023 and Appendix PA-4.9). The flow fields generated from the Culebra flow model are used for modeling actinide transport in the Culebra (see Appendix PA-4.10).

MASS-4.0 CREEP CLOSURE

The creep closure model considers porosity changes in the waste due to creep closure of salt. The creep closure model used in the CRA-2026 PA has been updated since the CRA-2019 PA (Vignes et al. 2023). The model used for creep closure of the repository is discussed in Appendix PORSURF-2026. Historical information on creep closure modeling is contained in Appendix PORSURF-2014.

MASS-5.0 REPOSITORY FLUID FLOW

Repository fluid flow assumptions have not changed from those used in the CRA-2019 PA. The Repository Fluid Flow conceptual model represents the long-term flow behavior of liquid and gas in the repository and its interaction with other regions where fluid flow may occur, such as the Salado, shafts, or an intrusion borehole. This model is not used to represent the interaction of fluids in the repository with a borehole during drilling. Due to replacement Panels 11 and 12 and the associated mains and drifts being added to the PA model, the implementation of the Repository Fluid Flow conceptual model was changed (see Appendix PA-4.). Although the model itself was not altered, the modified implementation of the conceptual model was subjected to a peer review and found to be adequate (Falta et al. 2021). Historical information on alternative conceptual models for brine inflow to the repository is contained in the CCA, Appendix MASS.7.

The first principle in the conceptual model for fluid flow in the repository is that gas and brine can both be present and mobile (two-phase flow), governed by conservation of mass and energy and by the two-phase Darcy's Law formulation for their fluxes (see Appendix PA-4.2). Consistent with typical multiphase flow concepts, each phase's flux is impeded by saturation-dependent relative permeability and coupled by capillary-pressure functions.

Fluid flow in the repository is affected by the following factors:

- The geometric association of pillars, rooms, and drifts; waste panel consolidation due to salt creep; and possible borehole locations.
- The varied properties of the waste areas resulting from creep closure and heterogeneous contents.
- Flow interactions with other parts of the disposal system.
- Reactions that generate gas.

The geometry of the panel around the intrusion borehole is consistent with the assumption that the fluid flow will converge toward or diverge from the borehole. The geometry represents a semicircular volume north of the borehole and a semicircular volume south of the borehole (representing radial flow in a subregion of a two-dimensional representation of the repository).

The computational mesh is locally refined around the intrusion borehole: cells immediately adjacent to the wellbore are much smaller in the horizontal directions than the coarser cells used elsewhere in the waste panels, producing a narrow band of fine cells in plan view. When a borehole is present, that refinement naturally aligns with radial convergent or divergent flow. In the undisturbed case, however, those fine cells remain even though no physical pathway exists there, giving the appearance of a lateral bottleneck. In reality, repository permeabilities are uniform at this scale, and fluid migration is controlled by the rate of inflow or outflow through the Salado (or a plugged hole), not by horizontal passage through the repository. The time scale involved and the permeability contrast between the repository and surrounding rock are sufficient so that the lateral flow that may occur in the repository is restricted by the rate at which liquid gets into or out of the repository, rather than by the rate at which it flows through the repository.

Gas generation is affected by the quantity of liquid in contact with metal and CPR waste materials and radionuclides in the waste for the case of radiolytic gas generation. However, the distribution of fluid in the repository can only be approximated. For example, capillary action can create wicking that would increase the overall region in which gas generation occurs, but capillary wicking occurs at pore-scale and cannot be resolved on our mesh, so it must be approximated in a cell-level bounding approach (Appendix PA-4.2.6 and CRA-2004, Chapter 6.0, Section 6.4.3.3). Therefore, as a bounding measure for corrosion and CPR biodegradation purposes, brine in the repository is distributed to an extent greater than estimated by the Darcy flow models, by the addition of a wicking term to the brine saturation predicted in the Darcy flow model.

Modeling flow within the repository is based on homogenizing the room contents into relatively large computational volumes. The approach ignores heterogeneities in disposal room contents that may influence gas and brine behavior by causing fluid flow among channels or creating preferential paths in the waste, bypassing entire regions. Isolated regions could exist for several reasons:

- They may be isolated by low-permeability regions of waste that serve as barriers.
- Connectivity with the interbeds may occur only at particular locations within the repository.
- The repository dip may promote preferential gas flow in the upper regions of the waste.

For the CCA, the adequacy of the repository homogeneity assumption was examined in screening analyses DR-1 (Webb 1995) and DR-6 (Vaughn et al. 1995a). These analyses used an additional parameter in the model for Salado flow to specify the minimum active (mobile) brine-flow saturation, or pseudo-residual brine saturation (analogous to the residual saturation

in capillary-pressure–saturation functions). Above this saturation, the normal descriptions of two-phase flow were applied (i.e., either the Brooks and Corey or van Genuchten and Parker relative permeability models). Below this minimum, brine was immobile, although it was available for reaction and possible consumption during gas generation reactions. The assumption of a minimum saturation limit was justified based on the presumed heterogeneity of the waste and the slight dip in the repository. The minimum active brine saturation was treated as an uncertain parameter and sampled uniformly between the values 0.1 and 0.8 during the analysis. This saturation limit was applied uniformly throughout the disposal room to bound the impact of heterogeneities on flow (Webb 1995; Vaughn et al. 1995a). Results of this analysis showed that releases to the accessible environment in the baseline case (homogenized) were consistently higher.

The EXP and operations (OPS)[5] regions were represented in the CCA by a fixed porosity of 18.0% and a permeability of 10^{-11} m^2. The combination of low porosity and high permeability conservatively overestimated fluid flow through these regions. It also limited the capacity of these regions to store fluids, potentially overestimating releases to the environment (Vaughn et al. 1995b).

Park and Hansen (2003) examined the possible effects of heterogeneity in waste container and waste material strength on room closure. The analysis of room closure found that the room porosity may vary widely depending on the type of waste container and the emplacement of waste in the repository. More recently, Reedlunn et al. (2023) examined the possible effects of criticality control overpack containers on the room closure. However, Hansen et al. (2003a) found that PA results are relatively insensitive to the uncertainty in room closure and room porosity. The conclusions of the separate PA are summarized in Appendix MASS-18.0.

MASS-5.1 Flow Interactions with the Creep Closure Model

Flow interactions with the creep closure model implemented in WIPP PA have not changed since the CCA. However, an updated creep closure model has been implemented for waste areas (see Appendix MASS-4.0 and Appendix PORSURF-2026). The dynamic effect of halite creep and room consolidation on room porosity is modeled only in the waste disposal region. Other parts of the repository, such as the open panel closure areas, EXP, WD, SOPS, and WOPS regions, are modeled assuming fixed (invariant with time) properties. In these regions, the permeability is held at a relatively high fixed value representative of unconsolidated material. At the same time, the porosity is maintained at relatively low values associated with highly consolidated material. This combination of low porosity and high permeability is assumed to conservatively overestimate flow through these regions and minimize the capacity of this material to store fluids (Vaughn et al. 1995c).

Intact panel closure areas (i.e., those areas with ROMPCS) are assumed to consolidate with the ROM salt approaching a condition similar to intact salt (Appendix PA-4.2.8). The consolidation of salt in these areas is not modeled using a porosity surface, but with permeability and

[5] The OPS region was defined in PAs prior to the CRA-2026 PA and is now called the SOPS region.

porosity properties that change instantaneously at two times during the 10,000-year regulatory period. The creep closure of open panel closure areas is treated in the same manner as that for the EXP, WD, SOPS, and WOPS regions (Zeitler et al. 2017 and Appendix PA-4.2).

MASS-5.2 Flow Interactions with the Gas Generation Model

No changes have been made to the gas generation model implemented in WIPP PA since the CRA-2019 PA.

Gas generation affects repository pressure, which in turn is an important parameter in other processes such as two-phase flow, creep closure, and fracturing of the interbeds and DRZ. Gas generation processes considered in PA flow calculations include radiolytic gas generation, anoxic corrosion, and microbial degradation. Prior to the CRA-2019 PA, radiolysis was excluded from PA flow calculations based on laboratory experiments and a screening analysis (Vaughn et al. 1995d) that concluded that radiolysis does not significantly affect repository performance. However, an updated screening analysis concluded that radiolysis does substantially impact repository total gas generation, and thus radiolytic gas generation was added to the gas generation model for the CRA-2019 PA (Day 2019).

In modeling anoxic corrosion and microbial degradation gas generation, the effective liquid in a computational cell is the computed liquid in that cell plus an adjustment for the uncertainty associated with wicking by the waste (see Appendix PA-4.2.6). Capillary action (wicking) is the ability of a material to carry a fluid by capillary forces above the level it would normally seek in response to gravity. Because the current gas generation model computes substantially different gas generation rates depending on whether the waste is wet or merely surrounded by water vapor, the physical extent of wetting could be important. A screening analysis (Vaughn et al. 1995d) examined wicking and concluded that it should be included in PA flow calculations.

The baseline gas generation model in Salado flow modeling accounts for corrosion of iron, microbial degradation of cellulose, and possibly plastics and rubber, and radiolysis of brine. The net reaction rates of corrosion of iron and microbial degradation of cellulose and possibly plastics and rubber depend directly on brine saturation: an increase in brine saturation will increase the net reaction rate by weighting the inundated portion more heavily and the slower humid portion less heavily.[6] To simulate the effect of wicking on the net reaction rate, an effective brine saturation, which includes a wicking saturation contribution, is used to calculate reaction rates rather than the actual brine saturation (see Appendix PA-4.2.6). The radiolytic gas generation rate also depends on brine saturation, but no associated humid rate is assumed, and there is no impact of wicking on the reaction rate. Dissolved radionuclides and a variable fraction of wetted solid radionuclides contribute to this process (see Appendix PA-4.2.5).

[6] In the CRA-2019 PA, nonzero values of humid steel corrosion rates (Zeitler 2018) were used for the first time.

MASS-6.0 GAS GENERATION

Repository fluid flow assumptions have changed from those used in the CRA-2019 PA. The gas generation model represents the possible generation of gas in the repository by radiolysis of brine, corrosion of steel, and microbial degradation of CPR materials. Brine radiolysis has been shown to be a potentially substantial source of gas generation that can impact repository pressure and brine saturation conditions in the repository (Day 2019). It was added to the gas generation model for the CRA-2019 PA (CRA-2019 Appendix MASS-6.1), and the same implementation is used in the CRA-2026 PA (Appendix GEOCHEM-2.1 and Appendix PA-4.2.5). Assumptions about the available surface area of iron have changed for the CRA-2026 PA (Appendix MASS-6.1). Additional gas and brine production and consumption reactions exist in the overall flow model.

As described in the Chemical Conditions Conceptual Model (Appendix GEOCHEM-2.2), the major reactions in the repository include the reactions of CPR, iron, and MgO with brine. The generation of water in these pathways is also considered. The reaction of iron hydroxide with H_2S, which consumes gas and produces water, was included in the CRA-2014 PA, but removed starting with the CRA-2019 PA, as the passivation of steel by H_2S is no longer considered a valid assumption (Appendix GEOCHEM-2.1.6). MgO reactions also include MgO hydration, which consumes water and produces $Mg(OH)_2$, and the carbonation of $Mg(OH)_2$, which is assumed to form $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$. It is assumed that the CO_2 preferentially reacts with the $Mg(OH)_2$versus the dry MgO. The reaction of $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$ to form magnesite and water is also included. All chemical reactions and species are tracked on a cell-by-cell basis. There is a finite amount of each chemical species in each cell. Once any of them is used up, that particular reaction ceases. The reactions that comprise the repository water balance implementation are more fully discussed in Appendix GEOCHEM-2.2.

Additional discussion of gas generation may be found in Appendix GEOCHEM-2.1, Appendix PA-4.2.5, and the CRA-2004, Chapter 6.0, Section 6.4.3.3. See the CCA, Appendix MASS-8.1 for historical information on the development of the CCA gas generation conceptual model.

MASS-6.1 Iron Surface Area

A key assumption in the model of gas generation due to iron corrosion has changed for the CRA-2026 PA. The assumed available surface area of iron is based on the type of waste containers assumed to be in the repository at closure. From the CCA through the CRA-2019 PA, the total surface area of iron-based metals for gas generation was calculated based on an estimated iron surface area per 55-gallon drum and an optimal loading of drums in the repository. For the CRA-2026 PA, the total iron surface area is instead calculated on a mass basis, with an estimated surface area per kilogram of iron inventory used in conjunction with the total iron inventory as part of the gas generation calculation. The iron surface area per mass of iron has been estimated based on container types used for emplaced waste (King 2021b). An optimally-loaded repository of 55-gallon drums is no longer assumed (Appendix GEOCHEM-2.3.1).

MASS-7.0 CHEMICAL CONDITIONS

The modeling assumptions of chemical conditions used in the CRA-2026 PA remain unchanged from those used in the CRA-2019 PA and were last changed in the CRA-2014 PA. The models used for chemical conditions in the repository are discussed in Appendix SOTERM-6.0 and Appendix GEOCHEM-3.2.

MASS-8.0 DISSOLVED ACTINIDE SOURCE TERM

The dissolved actinide source-term modeling assumptions used in the CRA-2026 differ from those used in the CRA-2019 PA. There has been a change in the assumptions about which states may coexist in the oxidation-state model. The models used for the dissolved actinide source term in the repository are discussed in Appendix SOTERM-6.0 and Appendix PA-4.3.

MASS-8.1 Change to Oxidation State Assumptions

From the CCA through the CRA-2019 PA, Np, Pu, and U actinides were assigned to either a low or high oxidation state (e.g., Pu(III) or Pu(IV)) to reflect epistemic uncertainty in which oxidation state would control solubility in post-closure repository conditions. Each state (low or high) was considered equally likely. The binary-state model assumed that all actinides exist in either a low or high oxidation state. In the CRA-2026 PA, the oxidation-state model was extended to include more combinations of states to represent the behavior of the different actinides across a range of redox (oxidation-reduction) potentials. For example, whereas Pu(IV) and Np(IV) were not assumed to coexist, they are now allowed to coexist in the repository. Accordingly, new parameterization was added for Np, Pu, and U to specify the likelihood of low or high oxidation state for each actinide (Kaplan et al. 2025 and Appendix GEOCHEM-4.1.5).

MASS-9.0 COLLOIDAL ACTINIDE SOURCE TERM

The colloidal actinide source term modeling assumptions used in the CRA-2026 have changed since the CRA-2019 PA (discussed in Appendix GEOCHEM-5.0). The models used for the colloidal actinide source, and actinide source term updates included in the CRA-2026 PA, are discussed in Appendix GEOCHEM-5.0, Appendix SOTERM-3.5, and Appendix PA-4.4.

MASS-9.1 Change to Microbial Colloid Model

From the CCA through the CRA-2019 PA, the microbial colloid model was parameterized solely on an elemental basis. For the CRA-2026 PA, the model has been extended to depend on the solubility-controlling oxidation state of each actinide (Kaplan et al. 2025).

MASS-10.0 SHAFTS AND SHAFT SEALS

The shafts and shaft seals modeling assumptions used in the CRA-2026 remain unchanged from those used in the CRA-2019 PA. Five shafts are incorporated into the combined shaft representation (Zeitler 2019), which lies between the EXP and WOPS. The models used for

shafts and shaft seals are discussed in Appendix PA-2004, Attachment MASS, Section MASS-12.0, and Appendix PA-4.2.7.

MASS-11.0 SALADO

The far-field Salado modeling assumptions used in the CRA-2026 PA remain unchanged from those used in the CRA-2019 PA and have not changed since the CCA. The purpose of this model is to represent the effects of fluid flow in the Salado on the long-term performance of the disposal system. The conceptual model is also discussed in the CRA-2004, Chapter 6.0, Section 6.4.5.

Fluid flow in the Salado is considered in the conceptual model of long-term disposal system performance for several reasons. First, some liquid could move from the Salado to the repository due to the considerable gradients that can form driving liquid flow toward the repository. This mechanism is important because such fluid can affect creep closure, gas generation, actinide solubility, and other processes occurring in the repository. Second, gas generated in the repository is thought to be capable of fracturing the Salado interbeds under certain conditions, creating higher permeability channels that could serve as pathways for lateral transport. The lateral transport pathway in intact Salado is also modeled, but it is considered unlikely to result in any significant radionuclide transport to the accessible environment boundary.

The fundamental principle in the conceptual model for fluid flow in the Salado is that the Salado is a porous medium within which gas and brine can both be present and mobile (two-phase flow), governed by conservation of energy and mass and by Darcy's Law for their fluxes (see Appendix PA-4.2). Consistent with typical concepts of two-phase flow, each phase can affect the other by impeding flow due to partial saturation (relative permeability effects) and by influencing pressure through capillary forces (capillary pressure effects). In the CCA, it was assumed that no waste-generated gas is present before repository closure. However, during the EPA completeness review of the CRA-2004, the representation of the gas generation rate was changed for the CRA-2004 Performance Assessment Baseline Calculation (PABC) (Cotsworth 2005) to represent the short-term, but initially faster, microbial gas generation rate (see Leigh et al. 2005, Section 2.3 and Appendix PA-4.2.2). Future states are modeled as producing gas by corrosion, microbial activities, and brine radiolysis. Should high pressure develop over the regulatory period, it is allowed to access MBs in the Salado.

Some variability in composition exists across different horizons of the Salado. The largest differences occur between the anhydrite-rich layers called interbeds and those dominated by halite. Within horizons dominated by halite, composition varies from nearly pure halite to halite plus several percent other minerals, in some instances including clay (see the CCA, Chapter 2.0, Section 2.1.3.4). The Salado is modeled as impure halite except for those interbeds that intersect the DRZ near the repository. This conceptual model and an alternative model that explicitly represented all stratigraphically distinct layers of the Salado near the repository (Christian-Frear and Webb 1996) produced similar results.

From other modeling and theoretical considerations, flow between the Salado and the repository is expected to occur primarily through interbeds that intersect the DRZ. Because of the large surface areas between the interbeds and surrounding halite, the interbeds serve as conduits for the flow of brine in two directions: from halite to interbeds to the repository or, for brine flowing out of the repository, from the repository into interbeds and then into halite. Because the repository is modeled as a relatively porous and permeable region, brine is most likely (but not constrained) to leave the repository through MB 139 below the repository due to the effect of gravity. If repository pressures become sufficiently high, gas is modeled to exit the repository via the MBs.

The effect of gravity may also be important in the Salado due to the slight and variable natural stratigraphic dip. For long-term performance modeling, the dip in the Salado within the domain is taken to be constant and one degree from north to south in the BRAGFLO grid.

Fluid flow in the Salado is conceptualized as either converging into the repository or diverging from it, as discussed in detail in the CRA-2004, Chapter 6.0, Section 6.4.2.1. Because the repository is not conceptualized as homogeneous, implementing a geometry for the conceptual model of convergent or divergent flow in the Salado is somewhat complicated and is discussed in the CRA-2004, Chapter 6.0, Section 6.4.2.1.

The conceptual model for Salado fluid flow has primary interactions with three other conceptual models. The interbed fracture conceptual model allows porosity and permeability of the interbeds to increase as a function of pressure. The repository fluid flow model is directly coupled to the Salado fluid flow model through the governing equations of flow in BRAGFLO (which cannot be distinguished in the governing equations), differing only in the modeled region and the assigned material parameters. The Salado model for actinide transport is directly coupled to the conceptual model for flow in the Salado through the process of advection. As a result, actinides are treated as nonreactive species with no hydrodynamic dispersion and no retardation. Additional information on the treatment of the Salado in PA is found in Appendix PA-4.2. See the CCA, Appendix MASS.13.2 for the historical information relating to the CCA Salado conceptual model. The Salado conceptual model is unchanged for the CRA-2026 PA.

MASS-11.1 High Threshold Pressure for Halite-Rich Salado Rock Units

The assumptions regarding the threshold pressure in the Salado in WIPP PA have not changed since the CCA. An important parameter used to describe the effects of two-phase flow is threshold pressure, which helps to determine the ease with which gas can enter a liquid-saturated rock unit. For a brine-saturated rock, the threshold pressure is defined as “equal to the capillary pressure at which the relative permeability to the gas phase begins to rise from its zero value, corresponding to the incipient development of interconnected gas flow paths through the pore network” (Davies 1991, p. 9).

The threshold pressure, as well as other parameters used to describe two-phase characteristics, has not been measured for halite-rich rocks of the Salado. The Salado, however, is thought to be similar in pore structure to rocks for which threshold pressures have been measured (Davies

1991). Based on this observation, Davies (1991) postulated that the threshold pressure of the halite-rich rocks in the Salado could be estimated if an empirical correlation exists between rocks with similar pore structure.

Davies developed a correlation between threshold pressure and intrinsic permeability applicable to the Salado halite. A similar correlation was developed for Salado anhydrites; subsequent testing confirmed that it accurately predicted threshold pressures. The correlation developed by Davies predicts threshold pressures in intact Salado halites on the order of 20 megapascals (MPa) or greater (Davies 1991). This threshold pressure predicted by correlation is much higher than that expected to persist in the repository so that, for all practical and predictive purposes, no gas will flow into intact Salado halites (see the CRA-2004, Chapter 6.0, Section 6.4.5.1).

Because threshold pressure helps control the flow of gas, and because the greatest volume of rock in the Salado is rich in halite, a high threshold pressure effectively limits the volume of gas that can be accommodated in the pore spaces of the intact host formation. Thus, high threshold pressure is conservative, because if gas could flow into the pore spaces of intact Salado halite, repository pressures could be reduced dramatically.

MASS-11.2 The Fracture Model

The assumptions regarding the fracture model implemented in WIPP PA have not changed since the CRA-2019 PA and are unchanged since the CCA. The purpose of this model is to alter the porosity and permeability of the anhydrite interbeds and the DRZ if their pressure approaches lithostatic, simulating some of the hydraulic effects of fractures with the intent that unrealistically high pressures (in excess of lithostatic) do not occur in the repository or disposal system. It simulates some hydraulic effects of fractures to attenuate development of unrealistically high pressures (i.e., much greater than lithostatic) within the repository or disposal system. The conceptual model is also discussed in the CRA-2004, Chapter 6.0, Section 6.4.5.2.

In the 1992 preliminary PA, repository pressures were shown to greatly exceed lithostatic pressure (14.8 MPa) if a large quantity of gas was generated. Pressures within the waste repository and surrounding regions were predicted to be roughly 20 to 25 MPa. It is expected that fracturing within the anhydrite MBs would occur at pressures slightly above lithostatic pressure, and this fracturing is implemented through pressure-dependent compressibility.

Two parametric behaviors must be quantified in the conceptual model. First, the change of porosity with pressure in the anhydrite MBs must be specified. A relatively simple equation, detailed in Appendix PA-4.2.4, relates porosity change to pressure change. This equation assumes that fracturing increases the compressibility of the interbeds. Model parameters are treated as fitting parameters and have little relation to physical behavior except that they affect porosity changes. The second parametric behavior is the change in permeability with pressure, which is incorporated through a functional dependence on porosity changes. It is assumed that a power function is appropriate for relating the magnitude of permeability increase to the

magnitude of porosity increase. The power function's exponent serves as a fitting parameter, which allows it to be set so that the permeability increase with porosity matches the desired behavior.

The model for flow in the Salado incorporates a one-degree dip that may affect fracture propagation direction. However, factoring in the accuracy of the finite difference grid, a fracture will develop radially outward. This model does not address fracture fingering or a preferential fracturing direction. Nonetheless, existing evidence does not support heterogeneous anhydrite properties that would contribute to preferential fracture propagation. This evidence is discussed in the CCA, Appendix MASS, Attachment 13-2.

The maximum enhanced fracture porosity controls the storativity within the fracture. The extent of the migration of the gas front into the MB is sensitive to this storativity. The additional storativity caused by porosity enhancement will mitigate gas migration within the MB. Enhanced permeability from the MB fracturing makes the gas more mobile leading to longer gas-migration distances. Thus, the effects of porosity enhancement at least partially counteract those of permeability enhancement in affecting the gas-migration distances.

Because intact anhydrite is partially fractured, the pressure at which porosity or permeability changes are initiated is close to the initial pressure within the anhydrite. Fracture treatment within the MBs will not contribute to early brine drainage from MBs because the pressures at these times are below the fracture initiation pressure.

The input parameters to the interbed fracture model (Feng and Kicker 2025) are chosen deterministically to produce the appropriate pressure and porosity response as predicted by a linear elastic fracture mechanics model, as discussed in Mendenhall and Gerstle (1993).

MASS-11.3 Flow in the DRZ

The modeling assumptions for flow in the salt DRZ remain unchanged from those used in the CRA-2019 PA and were last changed in the CRA-2014 PA. The conceptual model for the DRZ around the waste-disposal, OPS, and EXP regions has been chosen to provide a reasonably conservative estimate of fluid flow between the repository and the intact halite and anhydrite MBs. The conceptual model is also discussed in the CRA-2004, Chapter 6.0, Section 6.4.5.3.

The conceptual model implemented in the CCA PA used constant values for the permeability and porosity of the salt DRZ. A screening analysis examined an alternative conceptual model for the DRZ in which permeability and porosity changed dynamically in response to changes in pressure (Vaughn et al. 1995e). This analysis implemented a fracturing model for the salt DRZ. This fracturing model is used in the existing anhydrite interbed model. In this model, formation permeability and porosity depend on brine pressure, as described by Freeze et al. (1995, pp. 2-16 through 2-19) and Appendix PA-4.2.4. This model permits the representation of two important formation-alteration effects. First, pressure buildup caused by gas generation and creep closure within the waste will slightly increase porosity within the DRZ and offer additional fluid storage with lower pressures. Second, the accompanying increase in formation

permeability will enhance fluid flow away from the DRZ. An increase in porosity tends to reduce outflow into the far field. As a result, parameter values for this analysis were selected so that the DRZ alteration model greatly increases permeability while only modestly increasing porosity.

Two basic scenarios were considered in the screening analysis by Vaughn et al. (1995e): undisturbed repository performance and disturbed repository performance. Both scenarios included a one-degree formation dip downward to the south. Intrusion event E1 is considered in the disturbed scenario and consists of a borehole that penetrates the repository and pressurized brine in the underlying Castile. Two variations of intrusion event E1 were examined: E1 updip and E1 down-dip. In the E1 updip event, the intruded panel region was located on the north end of the waste disposal region, whereas in the E1 down-dip event, the intruded panel region was located on the south end of the disposal region. These two different geometries permitted evaluation of the possibility of increased brine flow into the panel region and the potential for subsequent impacts on contaminant migration. To incorporate the effects of uncertainty in each case (E1 updip, E1 down-dip, and undisturbed), a Latin hypercube sample size of 20 was used, for a total of 60 simulations. To assess the sensitivity of system performance on formation alteration of the DRZ, conditional CCDFs of normalized contaminated brine releases were constructed and compared with the corresponding baseline model conditional CCDFs that were computed with constant DRZ permeability and porosity values. Based on comparisons between conditional CCDFs, computed releases to the accessible environment were determined to be essentially equivalent between the two treatments. Since the two configurations were determined to have essentially equivalent impacts on releases, the intrusion borehole was assumed to intrude in the down-dip or south side of the repository where it is assumed brine would more readily accumulate.

Preliminary PAs considered alternative conceptual models that allowed for some lateral extent of the DRZ into the halite surrounding the waste disposal region and for the development of a transition zone between anhydrites A and B and MB 138 (WIPP Performance Assessment 1993, Volume 4, Figure 4.1-2 and Figure 5.1-2; Davies, Webb, and Gorham 1992; Gorham et al. 1992). The transition zone was envisioned as a region that had experienced some hydraulic depressurization and perhaps some elastic stress relief because of the excavation, but probably no irreversible rock damage and no large permeability changes. Modeling results indicated that including the lateral extent of the DRZ had no significant effect on fluid flow. Communication vertically to MB 138 was thought to be a potentially important process, however, and the model adopted for PA assumes that the DRZ extends upward to MB 138 and permeability is sampled over the same range used in the CCA Performance Assessment Verification Test (PAVT).

In 2003, the Salado Flow Peer Review considered and concurred with changes to repository modeling, which involved the Disturbed Rock Zone conceptual model. These changes included: specifying the “Option D” panel closure system; adjusting properties of the DRZ and nearby halite and anhydrite materials to represent potential flow around repository shaft and panel closure features; and replacement of the original 11-layer shaft seal model with a simplified

two-layer system (CRA-2004 Appendix PEER-2.1.1). The “Option D” panel closure system was later replaced by the ROMPCS (See Appendix PA-4.2).

MASS-11.4 Actinide Transport in the Salado

The assumptions used for actinide transport in the Salado remain unchanged from those used in the CRA-2019 PA and are unchanged since the CCA. This model is also discussed in the CRA-2004, Chapter 6.0, Section 6.4.5.4 and Appendix PA-4.3.4.

The Salado hydrology conceptual model assumes that actinide transport occurs solely through advection, i.e., the movement of material via bulk fluid flow. This model describes the porous medium and discusses how advection directly depends on fluid flow. Other processes that might disperse actinides, such as diffusion, hydrodynamic dispersion, and channeling in discrete fractures, are not included in the conceptual model. Since these processes will reduce actinide transport, it is conservative to ignore these processes.

To model Salado radionuclide transport, NUTS uses BRAGFLO's velocity field, pressures, porosities, and saturations as input. NUTS also incorporates other model parameters, such as the geometrical grid, residual saturation, material map, brine compressibility, and time step. The system averages these inputs over a specified number of time steps (five for the CRA-2026 PA calculations). NUTS then models radionuclide transport within all regions where BRAGFLO computes brine and gas flow. For contamination to take place, the brine must enter a repository section at some point during the 10,000-year regulatory period. Radioactive constituents of the waste in the repository are assumed to dissolve into the brine while the brine is in the repository; the radionuclides are then transported by advection to other regions outside the repository. Consequently, the results of NUTS are subject to all the uncertainties associated with BRAGFLO’s conceptual model and parameterization. Details of the source term, which specifies the types and amounts of radionuclides that are assumed to come into contact with the waste, are discussed in Appendix PA-4.3.

Transport by molecular dispersion is neglected. For materials of interest in the WIPP repository system, molecular diffusion coefficients are, at most, on the order of 4×10^{-10} m^2 per second. Thus, the simplest scaling argument using a time scale of 10,000 years leads to a molecular diffusion (that is, mixing) length scale of approximately 10 m (33 ft), which is negligible compared to the lateral advection length scale of roughly 2,400 m (7,874 ft) (the lateral distance from the repository to the accessible environment).

Transport by mechanical dispersion is also neglected (see the CRA-2004, Chapter 6.0, Section 6.4.5.4.2). Dispersion is quantified by dispersivities, which are empirical tensor factors proportional to flow velocity (to within geometrical factors related to flow direction). They account for both the downstream and cross-stream spreading of local extreme values in concentration of dissolved constituents. Physically, the spreading is caused by the condition that both the particle paths and velocity histories of once-neighboring particles can be vastly different because of material heterogeneities characterized by permeability variations. These variations arise from the irregular cross-sectional areas and tortuous inhomogeneous,

anisotropic connectivity between pores. Because of its velocity dependence, the transverse component of mechanical dispersivity tends to transport dissolved constituents from regions of relatively rapid flow (where mechanical dispersion has a larger effect) to regions of slower flow (where mechanical dispersion has a smaller effect). In the downstream direction, dispersivity merely spreads constituents in the flow direction. Conceptually, ignoring lateral spreading assures that dissolved constituents will remain in the rapid part of the flow field, which assures their transport toward the boundary. Similarly, ignoring longitudinal dispersivity ignores the elongation of a feature in the flow direction, which would delay the arrival of radionuclide constituents at the accessible environment. However, because the EPA release limits are time-integrated measures, the exact time of arrival is unimportant for constituents that arrive at the accessible environment, so long as arrival occurs within the assessment period (10,000 years).

MASS-12.0 GEOLOGIC UNITS ABOVE THE SALADO

The assumptions for modeling the geologic units above the Salado remain unchanged from those used in the CRA-2019 PA and remain unchanged since the CCA. The model for geologic units above the Salado was developed to provide a reasonable and realistic basis for simulations of fluid flow within the disposal system and detailed simulations of groundwater flow and radionuclide transport in the Culebra.

The basic stratigraphy and hydrology of the units above the Salado are described in the CRA-2004, Chapter 2.0, Section 2.1.3.5 through Section 2.1.3.10 and Section 2.2.1.4. Additional supporting information is contained in the CCA, Appendices GCR, HYDRO, and SUM. Details of the conceptual model for each unit are described in the CRA-2004, Chapter 6.0, Section 6.4.6 and additional information on units above the Salado is found in Appendix HYDRO-2014. The CCA, Appendix MASS, Section MASS-14.1 contains historical information relating to the conceptual models for units above the Salado. The conceptual models for the units above the Salado are unchanged for CRA-2026 PA.

The conceptual models for the geologic units above the Salado are based on the overall concept of a groundwater basin, as introduced in the CRA-2004, Chapter 2.0, Section 2.2.1.1 and in the CCA, Appendix MASS.14.2. However, simpler models for this region are implemented in PA. The geometries and properties of units in the different models applied to the units above the Salado are chosen to be consistent with the purpose of each model.

In the model for flow in the Salado, units above the Salado are represented with simplified models for layer thicknesses, material properties including porosity and permeability, and hydrologic properties such as pressure and initial fluid saturation. The model for Salado flow is not used to make inferences about groundwater flow in the units above the Salado. With respect to the units above the Salado, the model for flow in the Salado is used only for determination of fluid fluxes between the shaft or intrusion borehole and hydrostratigraphic units. For this purpose, the model for flow in the Salado does not need to resolve regional or local flow characteristics.

The Culebra is the only subsurface pathway modeled for radionuclide transport in units above the Salado. The model for flow and transport in the Culebra includes spatial variability in hydraulic conductivity and uncertainty and variability in physical and chemical transport processes. The assumptions for modeling fluid flow and transport in the Culebra are discussed in MASS-13.0.

MASS-13.0 CULEBRA

The modeling assumptions for the Culebra are unchanged from those used in the CRA-2019. The hydrogeologic setting for the Culebra models is described in Appendix TFIELD-2.0. Additional supporting information is contained in the CRA-2004, Chapter 2.0, Section 2.1 and Section 2.2, and in the CCA, Appendices GCR, HYDRO, and SUM.

The PA model for groundwater flow in the Culebra (1) provides a reasonable basis for simulating radionuclide transport in the Culebra, and (2) allows evaluation of the extent to which uncertainty about groundwater flow in the Culebra may contribute to uncertainty in the estimate of cumulative radionuclide releases from the disposal system. The computational model treats the Culebra as a confined two-dimensional aquifer with constant thickness and spatially varying transmissivity (see Appendix TFIELD-2.3.2 and TFIELD-5.2.4, and the CCA, Appendix MASS, Attachment 15-7). Flow is modeled as single-phase (liquid) Darcy flow in a heterogeneous porous medium. For historical information relating to the modeling of the Culebra, see the CRA-2004, Chapter 6.0, Section 6.4.6.2; Appendix PA-2004, Attachment MASS, Section MASS-15.1; and CRA-2014 Appendix TFIELD-4.0.

MASS-13.1 Flow in the Culebra

The conceptual model for flow in the Culebra is discussed in the CRA-2004, Chapter 6.0, Section 6.4.6.2. The CRA-2019 PA used the T-fields developed for the PABC-2009. The CRA-2026 PA used a new set of T-fields as described in Appendix TFIELD-2026 and in Bowman et al. (2023). A discussion of the adequacy of the two-dimensional assumption for PA calculations is included in the CCA, Appendix MASS, Attachment 15-7.

MASS-13.2 Dissolved Actinide Transport in the Culebra

This model represents the effects of advective transport and physical and chemical retardation on the movement of actinides in the Culebra. For actinide transport, the Culebra is represented as a dual-porosity medium, with advection, diffusion and dispersion processes in the advective porosity, and diffusion and sorption occurring in the diffusive porosity. This conceptual model is discussed in the CRA-2004, Chapter 6.0, Section 6.4.6.2.1. No changes have been made to this model since the CRA-2019 PA and it is unchanged since the CCA. For a historical presentation of this model, see Appendix PA-2004, Attachment MASS, Section MASS-15.2.

MASS-13.3 Colloidal Actinide Transport in the Culebra

This model represents the effects of colloidal actinide transport in the Culebra. This model is discussed in the CRA-2004, Chapter 6.0, Section 6.4.6.2.2 and Appendix PA-2004, Attachment MASS, Attachments 15-2, 15-8, and 15-9. Humic colloids are assumed to be transported in the same way as dissolved actinides, while intrinsic, microbial, and mineral fragment colloids are assumed not to be transported in the Culebra (Appendix PA-6.4.3). No changes have been made to this model since the CRA-2019 PA and it remains the same since the CCA. Additional information and historical information on colloidal actinide transport and retardation in the Culebra can be found in Appendix PA-2004, Attachment MASS, Section MASS-15.3.

MASS-13.4 Subsidence Caused by Potash Mining in the Culebra

The mining-related modeling assumptions used in the CRA-2026 PA remain unchanged from those used in the CRA-2019 PA and are unchanged since the CCA. The mining subsidence model incorporates the effects of potash mining in the McNutt Potash Zone on disposal system performance (see Appendix SCR-2014, FEP H13, FEP H37, and FEP H38). Provisions in 40 CFR Part 194 describe a conceptual model and elements of a mathematical model for these effects. The DOE has implemented the EPA conceptual model (40 CFR § 194.32(b), U.S. EPA 1996) to be consistent with EPA criteria and guidance; this model is described in the CRA-2004, Chapter 6.0, Section 6.4.6.2.3. Additional information on the implementation of the mining subsidence model is available in the CCA, Appendix MASS, Attachments 15-4 and 15-7; and Wallace 1996.

The principal parameter in this model is the range assigned to a factor by which hydraulic conductivity in the Culebra is increased (see the CCA, Appendix MASS, Attachment 15-4). As allowed in supplementary information to 40 CFR Part 194, hydraulic conductivity is the only parameter changed to account for the effects of mining.

Mining has been included in scenario development for WIPP PA since the earliest work on this topic (U.S. DOE 1980 [pp. 9-145 through 9-148]; Hunter 1989; Marietta et al. 1989; Guzowski 1990; Tierney 1991; WIPP Performance Assessment 1991a, 1991b, 1991c, 1991d). These early scenario developments considered both solution and room-and-pillar mining. The focus was generally on the effects of mining outside the disposal system. In the CCA FEPs screening, solution mining was screened out during scenario development (see Appendix SCR-2014, FEP H58 and FEP H59). The two primary effects of mining considered were (1) changes in the hydraulic conductivity of the Culebra or other units, and (2) changes in recharge as a result of surface subsidence. These mining effects were not formally incorporated into the quantitative assessment of repository performance in preliminary PAs.

MASS-14.0 INTRUSION BOREHOLE

The assumptions used to model intrusion boreholes have been updated from those used in the CRA-2019 PA. For DBR modeling, a new panel group (Other) and a new representative borehole were introduced (see Appendix MASS-14.2) as a result of considering the proposed

replacement panels. For modeling releases from the Culebra, an additional release point to the Culebra has been added (see Appendix MASS-14.5).

The inclusion of intrusion boreholes in PA increases the number of release pathways for radionuclides from the disposal system identified for the undisturbed repository. Direct releases to the surface may occur during drilling as particulate material from cuttings, cavings, and spallings are carried to the surface. Also, dissolved actinides may be carried to the surface in brine during drilling. Once abandoned, the borehole provides a possible long-term pathway for fluid flow, such as between a hypothetical Castile brine reservoir, the repository, and overlying units. This topic is also addressed in the CRA-2004, Chapter 6.0, Section 6.4.7, Appendix SCR-2014 (FEP H1 and FEP H21), and CRA-2019 Appendix MASS-14.0.

MASS-14.1 Cuttings, Cavings, and Spallings Releases during Drilling

The assumptions regarding solids releases during drilling as applied in WIPP PA have not changed since the CRA-2014 PA. The cuttings, cavings, and spallings models estimate the quantity of actinides released as solids directly to the surface during drilling through the repository. The releases are caused by three mechanisms: the drill bit boring through the waste (cuttings); the drilling fluid eroding the walls of the borehole (cavings); and high repository gas pressure causing solid material failure and entrainment into the drilling fluid in the wellbore (spallings). See the CRA-2004, Chapter 6.0, Section 6.4.7.1, and references to other appendices cited in that section for additional information. Stochastic uncertainty in parameters relevant to these release mechanisms is addressed in the CRA-2004, Chapter 6.0, Section 6.4.12. The conceptual model for cuttings, cavings, and spallings is discussed in three parts because of the different processes that produce the three types of releases.

Cuttings are materials removed to the surface through drilling mud by the direct mechanical action of the drill bit. The volume of waste removed to the surface is a function of the repository height and the drill bit area. The principal parameter in the cuttings model is the drill bit diameter (Feng and Kicker 2025).

Cavings are materials introduced into the drilling mud by the erosive action of circulating drilling fluid on the waste in the walls of the borehole annulus. Erosion is driven solely by the shearing action of the drilling fluid (or mud) as it moves up the borehole annulus. Shearing may be caused by either laminar or turbulent flow. The principal parameters in the cavings model are the properties of the drilling mud, drilling rates, the drill string angular velocity, and the shear resistance of the waste (see Appendix MASS-14.1.2). Details on the sampled parameters used in the cavings model, the drill string angular velocity, and the effective shear resistance to erosion are presented in Feng and Kicker (2025).

Spallings are solids introduced into the wellbore by the fluid pressure difference between the repository and the bottom of the wellbore. If the repository pressure is sufficiently high (above about 12 MPa) relative to the well bottom-hole pressure (about 8 MPa), the stress state in the repository may cause repository solids to fail in the vicinity of the wellbore. In turn, these solids may become entrained in the gas flowing toward the well, ultimately being carried to the land

surface and constituting a release. The principal parameters in the spallings model are the gas pressure in the repository when it is penetrated and properties of the waste, such as permeability, tensile strength, and particle diameter. Because the release associated with spallings is sensitive to gas pressure in the repository, it is strongly coupled to the BRAGFLO-calculated conditions at the time of penetration.

MASS-14.1.1 Historical Context of Cuttings, Cavings, and Spallings Models

Cuttings and cavings releases are straightforward. The analytical equations governing erosion (cavings) based on laminar and turbulent flow (Appendix PA-4.6) have been implemented in the code CUTTINGS_S. Using selected input based on assumed physical properties of the waste and other drilling parameters, this code calculates the final caved diameter of the borehole that intersects the waste.

The various approaches used for spallings up to the CCA PA are documented in the CCA, Appendix MASS-16.1.1. Since the CCA PA, the spallings model has been extensively revised and has changed fundamentally from an end-state erosional model to a mechanically based, coupled material failure and transport model (WIPP Performance Assessment 2003a). This model is implemented in the code DRSPALL. An implementation error in the DRSPALL code was found and corrected for the CRA-2019 PA (Kicker et al. 2015). A discussion tracing the historical steps from the CCA erosional model to the current DRSPALL model can be found in Appendix PA-2004, Attachment MASS, Section MASS-16.1.1.

MASS-14.1.2 Waste Mechanical Properties

Waste mechanical properties used in the CRA-2026 PA are unchanged from those used in the CRA-2019 PA. For intrusion events considered in WIPP PA, drilling mud flowing up the borehole will apply a hydrodynamic shear stress on the borehole wall. The WIPP PA uses the parameter BOREHOLE:TAUFAIL to represent the hydrodynamic shear strength of the waste in the numerical code CUTTINGS_S (see Appendix PA-4.6). It is officially called the “effective shear strength for erosion,” but it is more commonly known as the “waste shear strength.” For the CRA-2014 PA, results of experiments performed on surrogate materials for degraded waste were used to refine the range of values for the waste shear strength. (CRA-2014 Appendix PA-1.1.5).

MASS-14.1.3 Mechanistic Model for Spall

The modeling assumptions for spallings remain unchanged from those used in the CRA-2019 PA and are unchanged since the CRA-2004 PABC. In the CRA-2004 PA, an approach to modeling the WIPP spallings process was developed to address peer-review concerns during the original certification process (see the CCA, Chapter 9.0, Section 9.3.1.2 and Appendix PEER-2004, Section PEER-2004 3.0). Instead of focusing on the end state after penetration, as was done in the original CCA erosional model, the new model sought to capture the system behavior from just before penetration through to the end state. In doing so, many more phenomena were included in the model. Considered in this new conceptual model was unsteady, convergent gas

flow from the repository toward the wellbore that caused mechanical stress and potential failure of solids near the face of the wellbore. Pressure in the cavity at the point of penetration was balanced by the mud column in the wellbore and the repository pressure.

The spallings model (WIPP Performance Assessment 2003a) includes:

1. A wellbore flow model that transports mud, repository gas, and waste solids from the repository level to the land surface.

2. A fluidized bed model that evaluates the potential for failed particulate waste to fluidize and become entrained in the wellbore flow.

The wellbore flow model in the spallings model uses a one-dimensional geometry and assumes a compressible, viscous, isothermal, homogeneous mixture of mud, gas, and solids. Standard mass and momentum balances, friction loss equations, and slurry viscosity equations are used. Wellbore flow model results were successfully verified against those from an independent commercial code for several test problems (WIPP Performance Assessment 2003b).

The spallings model applies the fluidized bed theory to determine the mobilization of failed material to the flow stream in the wellbore. If the escaping gas velocity exceeds the minimum fluidization velocity, failed material is fluidized and entrained for transport to the land surface. If gas velocity is too low to fluidize the bedded material, the cavity size is allowed to stabilize. The spall volumes predicted by the spallings model are based on the following conservative assumptions for material properties and for the flow geometry within the repository:

- The particle size distribution for spallings is based on a detailed analysis (Wang 1997) of data from an expert elicitation (Carlsbad Area Office Technical Assistance Contractor [CTAC] 1997). This analysis considered several limiting cases in developing a conservative distribution for mean particle size ranging from 1 millimeter to 10 cm (Hansen et al. 2003b).

- The shape factor for fluidization of particles has a potential range from 0 to 1.0 (unitless). Smaller values of the shape factor denote particles that are less spherical, and therefore more easily fluidized and transported in the flow. The shape factor is conservatively set to a value of 0.1 (Lord 2003).

- The tensile strength of the waste assigned for the spalling process is uncertain, ranging from 0.12 MPa to 0.17 MPa (Hansen et al. 2003b). Tensile strength data were measured in laboratory experiments on surrogate materials chosen to conservatively represent highly degraded residuals from typical wastes. The given range is felt to represent extreme, low-end tensile strengths because it does not account for several strengthening mechanisms, such as MgO hydration and halite precipitation/cementation (Hansen et al. 1997).

- The spallings model uses a hemispherical geometry for the flow field and cavity in the waste. This conceptual model is appropriate when the drill bit first penetrates the repository. But, as the drill bit passes completely through the compacted waste, the flow

field transitions toward a cylindrically symmetric geometry. This transition is important because the largest spall release volumes are predicted to occur at late times, well after the drill bit has penetrated through the waste, and because the spall volumes predicted for a cylindrical geometry are less than for the hemispherical geometry (Lord et al. 2003).

In summary, the conservative assumptions for waste properties, the waste flow geometry, and the driller's actions provide very conservative spalling release volumes (see also Appendix PA-4.7 for a description of the spallings model).

MASS-14.1.4 Calculation of Cuttings, Cavings, and Spallings Releases

The modeling assumptions relating to the calculations of cuttings, cavings and spallings releases have not changed from those used in the CRA-2019 PA and were last changed in the CRA-2004 PA. As detailed in Appendix PA-6.4.2, cuttings and cavings releases for intrusions into CH-TRU waste are computed by multiplying the volume released by the average radioactivity concentration from three independently selected waste streams, consistent with the conceptual assumption that waste streams are randomly emplaced in waste stacks that are three drums high (note that the radioactivity concentration is scaled from the input value by the fraction of repository volume assumed to be occupied by waste). Cuttings and cavings releases for RH-TRU waste are calculated in a similar manner to CH-TRU waste, with the exception that a single waste stream is selected, consistent with the assumption that RH-TRU waste is randomly emplaced in a manner such that a single waste canister is encountered by a hypothetical drilling intrusion. The probability that an intrusion that intersects waste intersects CH-TRU or RH-TRU waste is based on the repository footprint areas associated with CH-TRU and RH-TRU waste.

For the CRA-2026 PA, the assumed repository footprint and waste volume have changed. The repository footprint has increased due to the consideration of two replacement panels. However, it was also recognized that despite the increased footprint, the maximum volume of mixed TRU waste permitted by the Land Withdrawal Act (LWA) cannot be accommodated within the physical space provided by 12 panels. Ward (2025) used a statistical analysis of Waste Data System emplacement data for Panels 1 through 7 in a recommendation to reduce the assumed LWA total inventory to 157,831.92 m^3, which comprises 156,247.12 m^3 of CH-TRU waste and 1,584.80 m^3 of RH-TRU waste. This recommendation accounts for the LWA TRU waste emplaced volumes reported for Panels 1 through 7, with 16,909.71 m^3 of CH-TRU waste and 244.61 m^3 of RH-TRU waste assumed to be emplaced by the time of closure in each of Panels 8 through 12.

The effect of the random emplacement assumption on PA results was examined in a separate PA (Hansen et al. 2003a) in which cuttings and cavings releases were computed by assuming that each intrusion encounters only a single waste stream. The differences in repository performance (determined by comparing the mean CCDFs across releases) were minor. For more details on the analysis, see Appendix PA-2004, Attachment MASS, Section MASS-21.0.

King et al. (2024) considered a hypothetical case of a single waste panel filled with waste from high-activity dilute-and-dispose plutonium waste streams. In addition to an increase in gas generation in that panel (resulting in increased spallings releases), there was also a decrease in brine saturation (resulting in decreased DBRs). The study concluded that 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. This supports the random emplacement assumption.

Because spallings may release a relatively large volume of material (exceeding 4 m^3), spalling releases for intrusions into CH-TRU waste are computed by multiplying the volume of spalled material by the average CH-TRU waste concentration of radioactivity in the repository at the time of the intrusion. A separate PA (Hansen et al. 2003a) compared spalling releases computed using the average concentration of radioactivity in the waste to spalling releases computed using the radioactivity of a single, randomly selected waste stream. The analysis determined that the assumption had only a minor effect on the mean CCDF for releases. For more details on the analysis, see Appendix PA-2004, Attachment MASS, Section MASS-21.0.

MASS-14.2 Direct Brine Releases during Drilling

The DBR modeling assumptions used in the CRA-2026 PA were changed from those used in the CRA-2019 PA. A new panel group (Other) was introduced, a new representative borehole was introduced, and panel neighbor relationships associated with DBRs have also changed (changes described below). This model provides a series of calculations to estimate the quantity of brine released directly to the surface during drilling. The DBRs may occur when a driller penetrates the WIPP repository and unknowingly brings contaminated brine to the surface during drilling (these releases are not accounted for in the cuttings, cavings, and spallings calculations, which model only the solids removed during drilling). Appendix PA-4.8 describes the DBR model used for the CRA-2026 PA. The CCA, Appendix MASS, Attachment 16-2 describes the DBR model used for the CCA PA. Due to the replacement Panels 11 and 12 and the associated mains and drifts being added to the PA model, the implementation of the Direct Brine Release conceptual model was changed. The modified implementation of the conceptual model was subjected to a peer review and found to be adequate (Falta et al. 2021). The conceptual model for DBRs is discussed in Appendix PA-4.8, the CRA-2004, Chapter 6.0, Section 6.4.7.1.1, and McCormick et al. 2024.

The DBR calculations are performed for four intrusion points (designated Lower, Middle, Upper, and Other) in the waste areas corresponding to subsequent intrusions in the “same,” “connected,” “adjacent,” and “non-adjacent” panels, respectively. Up through CRA-2019, three intrusion points were used. A fourth intrusion point in a new (“Other”) panel group was added for the CRA-2026 (Docherty and King 2023) for estimating DBR volumes from initial intrusions into the proposed replacement waste panels (i.e., Panels 11 and 12) in the WROR and for intrusions subsequent to the initial intrusion when the initial intrusion is in a different half (i.e., West vs. South) of the repository compared to the subsequent intrusion.

Table MASS-66. Use of Representative Boreholes for DBR

Representative Borehole	Initial Intrusion: Intruded Panel	Subsequent Intrusion: Panel Group
Lower	5	Same
Middle	3, 4, 6, 9	Connected
Upper	1, 2, 7, 8, 10	Adjacent
Other	11–12	Non-Adjacent

MASS-14.3 Long-Term Properties of the Abandoned Intrusion Borehole

The long-term treatment and assumptions used to represent boreholes in the CRA-2026 PA remain unchanged from those used in the CRA-2004 PABC. See Appendix PA-2004, Attachment MASS, Section MASS-16.3 and Appendix PA-4.2.9 for the borehole modeling implementation used in the CRA-2026 PA.

MASS-14.4 Consideration of Waste in Panel 9

Despite the planned operational change to abandon waste emplacement in Panel 9, waste has continued to be modeled in Panel 9 since the CRA-2019 PA (Zeitler et al. 2017). Modeled intrusions into Panel 9 continue to be assumed to intersect waste. Continuing to model the same mass of waste as if it is located in Panel 9 results in somewhat larger DBR and spallings releases compared to the hypothetical case of the same mass being relocated to an arbitrary location further north (Zeitler et al. 2017). Zeitler et al. (2017) also found that the potential non-conservative assumption of not considering DBRs from both the empty Panel 9 and the hypothetical Panel 9 replacement is more than covered by the conservative assumptions of the panel neighbor redefinitions (see CRA-2019 Appendix MASS-14.2). The release increases due to panel reneighboring exceed the release decreases due to not considering DBRs from an empty panel. Thus, there is no need to model intrusions into open areas—i.e., areas that do not initially contain solid waste, but may contain contaminated brine at later times. The inclusion of waste Panels 11 and 12 for the CRA-2026 PA does not change the assumption of waste in Panel 9. For CRA-2026 it is appropriately conservative, with respect to releases, to continue to model waste within the existing Panel 9.

MASS-14.5 Multiple Release Points into Culebra

Prior to the CRA-2026 PA, only a single point was assumed in CCDFGF for releases from the repository into the Culebra (Wilgus and Brunell 2025). The single point was located at the center of the 10-panel representation of the repository. For the CRA-2026 PA, an additional release point is located above Panels 11 and 12 to account for variability in radionuclide travel times across the repository footprint (Appendix PA-4.10).

MASS-15.0 CLIMATE CHANGE

The climate change model remains unchanged from that used in the CRA-2019 PA and is unchanged since the CCA. Consideration of climate is limited to conditions that could result from reasonably possible natural climatic changes. The model is not intended to provide a quantitative prediction of future climate, nor to address uncertainty in system properties other than estimated cumulative radionuclide releases which may be affected by climate change. See Appendix PA-2004, Attachment MASS, Sections MASS-17.0 and MASS-17.1 for information on the climate change model. The implementation of this model in PA is also discussed in the CRA-2004, Chapter 6.0, Section 6.4.9 and CRA-2009 Appendix PA-2.1.4.6. See also the CCA, Appendix CLI for information on expected climate variability over the 10,000-year regulatory time period.

MASS-16.0 CASTILE BRINE RESERVOIR

The modeling assumptions of the Castile brine reservoir in the model for Salado flow in the CRA-2026 PA remain unchanged from those used in the CRA-2019 PA and were last changed in the CRA-2004 PA. The conceptual model for the hypothetical brine reservoir is included in the PA to estimate the extent to which uncertainty about the existence of a brine reservoir under the waste-disposal region may contribute to uncertainty in the estimate of cumulative radionuclide releases from the disposal system. The conceptual model is not intended to provide a realistic approximation of actual brine reservoirs under the waste disposal region in terms of size or number; reservoirs may have a range of sizes, but a single reservoir is modeled. Data are insufficient to determine whether such a brine reservoir exists. Outside the modeled reservoir, the Castile Formation is treated as an impermeable unit in PA and it plays no role in the analysis except to separate the Salado from the modeled Castile brine reservoir in the BRAGFLO grid (see Appendix PA-4.2). In human-intrusion scenarios, the hypothetical brine reservoir can be penetrated by an intrusion borehole connecting it to the repository. The amount of brine that can enter the repository from the brine reservoir is important because brine is required for gas generation reactions and can transport radionuclides in solution, contributing to potential releases.

The properties of the hypothetical brine reservoir defined for PA include permeability, porosity, pore volume, initial pressure, and various two-phase flow parameters. Values assigned to these properties were chosen to either be consistent with available data and analyses of borehole penetrations of brine reservoirs in the region or to provide a reasonable response in the BRAGFLO model. In an update for the CRA-2026 PA, the Castile reservoir pore volume and porosity parametrizations were updated to be consistent with a two-domain hydrogeologic model that was shown to describe the brine flow and well pressures from two wells (WIPP-12 and ERDA-6) that produced Castile brine (Gross and Gjerapic 2022).

The current implementation of the brine reservoir in the Salado flow and transport models is based on the CCA PAVT (U.S. EPA 1998), the constant productivity ratio approach used for the CRA-2004 PA, and the recent changes noted above. See Appendix PA-4.2.10 for the details on the implementation in the CRA-2026 PA.

Basic geologic information about the Castile is given in the CRA-2004, Chapter 2.0, Section 2.1.3.3. The hydrology of the known brine reservoirs is discussed in the CRA-2004, Chapter 2.0, Section 2.2.1.2.2. The treatment of the hypothetical brine reservoir in PA is discussed in the CRA-2004, Chapter 6.0, Section 6.4.8. See the CCA, Appendix MASS, Attachment 18.1 for historical information on the Castile brine reservoir model.

MASS-17.0 CLAY SEAM G MODELING ASSUMPTIONS

The modeling assumptions used to represent Clay Seam G are described in Appendix PA-2004, Attachment MASS, Section MASS-20.0. No changes were made to these assumptions since the CRA-2019 PA and were last changed for the CRA-2004 PA. These assumptions have been used in the CRA-2026 PA.

MASS-18.0 EVALUATION OF WASTE STRUCTURAL IMPACTS, EMPLACEMENT, AND HOMOGENEITY

The assumption of random waste emplacement remains unchanged since the CRA-2019 PA and has remained unchanged since the CCA. The DOE assumes random placement of TRU waste in the WIPP repository and this is reflected in the current conceptual and numerical models. The EPA reviewed these models and their results and determined that the DOE had adequately modeled the random placement of waste in the disposal system. The CCA PA also assumed that all waste could be modeled as if it were emplaced in 55-gallon drums. In accordance with the requirements of 40 CFR § 194.24(d) (U.S. EPA 2004), all PAs have assumed that waste is emplaced in a random or homogeneous manner. The PAs executed in support of compliance applications have not specifically accounted for heterogeneity in waste materials or in waste containers. Details of previous investigation into this assumption are found in MASS-14.1.4 and CRA-2014 Appendix MASS-19.0. The effect of random emplacement was reevaluated for high plutonium loading (King et al. 2024 and Appendix MASS-14.1.4). For the CRA-2026 PA, the assumption of random emplacement is used.

MASS-19.0 REFERENCES

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