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SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

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Revision 0

Analysis Plan for the Replacement Panels Performance Assessment

Task 4.4.1.2.1

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Authored by:	Clifford Hansen	Signature on File	01/24/2022
	Print Name	Signature	Date
Reviewed by:	Todd Zeitler	Signature on File	01/24/2022
	Print Name Technical Reviewer	Signature	Date
Reviewed by:	Shelly R. Nielsen	Shelly R. Nielsen	1-24-2022
	Print Name Quality Assurance Reviewer	Signature	Date
Approved by:	Steve Wagner		1/24/2022
	Print Name Department Manager	Signature	Date

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1 Introduction and Objectives

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

The DOE demonstrates compliance with the containment requirements according to the Certification Criteria in Title 40 CFR Part 194 by means of performance assessment (PA) calculations performed by Sandia National Laboratories (SNL). WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure. WIPP PA models are used to support the repository recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999.

The models used in PA are maintained and updated with new information as part of an ongoing process. Improved information regarding important WIPP features, events, and processes (FEPs) typically results in refinements and modifications to PA models and the parameters used in them. Planned changes to the repository and/or the components therein also result in updates to WIPP PA models.

As currently certified, WIPP includes ten excavated panels for the placement of waste. For operational reasons, not all of the volume of the ten excavated panels will be used for waste disposal. The DOE plans to excavate two panels, termed replacement panels, to provide an equivalent disposal capability, and may consider excavating up to seven panels beyond the two replacement panels, defined here as additional panels.

This analysis plan describes the models and parameters to be used in the Replacement Panels Performance Assessment (RPPA) to quantify the long-term performance of a repository layout that includes nine new (replacement and additional) panels.

1.1 Analysis Baseline

The analysis described in this plan is based on the models and parameters used for the CRA-2019 (DOE, 2019). The RPPA differs from the CRA-2019 as follows:

1. Waste inventory parameters will be updated based on the 2021 ATWIR and described in a new Performance Assessment Inventory Report (PAIR).
2. Actinide solubilities will be updated with the updated inventory parameters and thermodynamic database changes.
3. Repository area and volume parameters are updated to account for the new panels.
4. An update to the iron surface area used for gas generation from iron corrosion in the Salado Flow model.
5. An update to the calculation of waste area pressures at the time of closure.
6. The grid for the Salado flow model is modified to accommodate new panels.
7. The grid for computing direct brine releases (DBRs) is modified to account for the new panels.

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8. Logic for assigning panel neighbors is extended to account for the new panels.
9. The procedure for calculating releases due to transport through the Culebra is modified to account for the extended footprint of the repository due to the new panels.
10. The PRECCDFGF and CCDFGF codes are modified to accommodate new panels and the modified procedure for calculating Culebra releases.

A performance assessment based on CRA-2019, the Additional Panels Performance Assessment (APPA), considered many but not all of the above changes (Hansen, 2021a; Brunell et al., 2021). In particular, the APPA considered items 6, 7, and 8 from the above list, and in part items 3 and 10. The APPA included corrections to actinide solubilities from the CRA-2019 values, which will be combined with an updated inventory for the RPPA. The APPA plan (Hansen, 2020) contemplated changes to the procedure for calculating releases through the Culebra, but the APPA analysis was conducted using the CRA-2019 approach (Brunell et al., 2021).

The RPPA uses the dimensional model of the repository (item 3) and the same grids (items 6, 7 and 8) as the APPA. The RPPA analysis differs from the APPA by considering a new inventory (item 1), the effect of a new inventory on actinide solubilities (item 2), updates to the iron surface area and initial pressure calculations (items 4 and 5), and the revised procedure for releases through the Culebra (items 9 and 10).

1.2 Replacement and Additional Panels

The DOE plans to excavate two replacement panels to provide disposal volume equivalent to the unused volume in the ten original panels. In the future the DOE may consider excavating additional waste panels beyond the two replacement panels to provide sufficient repository volume for the statutory limit of waste. This analysis assumes that the repository includes nine new waste panels (two replacement and seven additional, numbered 11 through 19) to the west of the current repository, as illustrated in Figure 1. Panels 11 through 19 will be similar to Panels 1 through 8, except that the abutment pillars (between the waste rooms and the access drift) are increased from 61.0 m (200 ft) to 122 m (400 ft) and the isolation pillars (separating any two panels) are increased from 61.0 m (200 ft) to 91.5 m (300 ft).

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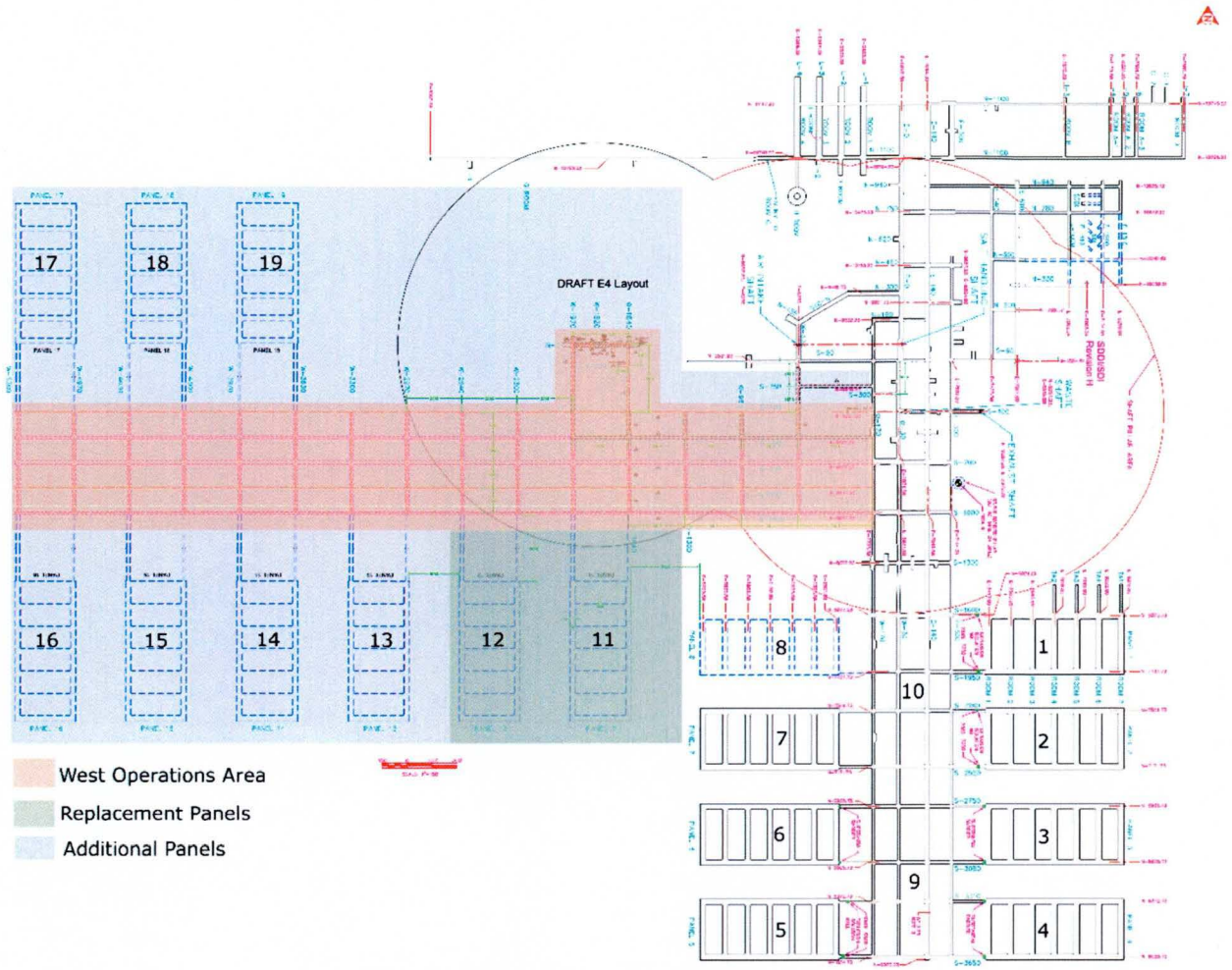

Figure derived from Sjomeling, (2019).

Figure 1. Current Repository Footprint, Replacement Panels and Additional Waste Panels

1.3 Panel Closures

Panel closures for the new panels comprise 100 feet of run-of-mine (ROM) salt in the intake and exhaust drifts, the same as for the waste panels in the current repository. The analysis assumes that there are no panel closures in the drifts that connect the west panels to the operations and experimental areas (Sjomeling, 2019).

1.4 Non-Waste Areas

Five access drifts running east-west connect the new panels with the rest of the repository. This analysis assumes that no waste is emplaced in the west access drifts.

1.5 Shafts

There are four shafts currently located in the repository north end, namely a salt handling shaft, an exhaust shaft, a waste shaft, and an air intake shaft. In the wake of the 2014 radiological release event at the WIPP site, an upgraded ventilation system is planned that will provide sufficient

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airflow necessary for the resumption of increased-rate disposal operations in the future. The primary components of the upgraded ventilation system include an additional shaft in the north end of the repository and associated drifts to connect the additional shaft to the operations area of the repository. The additional shaft will be represented in the repository modeled in the RPPA.

2 Approach

The RPPA is organized as a sequence of tasks:

1. Review of FEPs and conceptual models.
2. Generating a sample of uncertain parameters.
3. Salado flow modeling.
4. Updates to inventory
5. Updates to radionuclide solubilities.
6. Salado transport modeling.
7. Modeling of direct releases.
8. Culebra flow and transport modeling.
9. Calculation of complementary cumulative distribution functions (CCDFs) that quantify potential releases from the repository.
10. Calculate Culebra travel times.
11. Conduct sensitivity analyses.

Each task is detailed in the subsequent sections. Deviations from the planned approach will be detailed in analysis reports and in revisions to this plan, as warranted.

2.1 Review of FEPs and Conceptual Models

The addition of excavated areas to the west of the repository, and the proposed emplacement of waste in these areas, may affect the screening of FEPs for the PA and the conceptual models that represent FEPs.

For the APPA a FEPs assessment was performed according to SP 9-4, Performing FEPs Baseline Impact Assessments for Planned or Unplanned Changes (Kirkes, 2021). The FEPs assessment found that no changes to FEP screening decisions were warranted.

For the APPA, the conceptual models used in the PA were reviewed to identify those models that are affected by the proposed changes (Hansen, 2021b). The review concluded that 3 of the 24 conceptual models were affected:

- Disposal System Geometry
- Repository Fluid Flow
- Direct Brine Release

The Additional Panels Performance Assessment (APPA) Changed Conceptual Models Peer Review examined the changes affecting these three conceptual models and concluded that the changed conceptual models provide an adequate and reasonable representation of the repository system (Falta et al., 2021).

The primary differences between the RPPA and the APPA are the revised inventory and the procedure for computing releases through the Culebra. The revised inventory is expected to be similar to previous inventories provided to PA. The changed procedure for computing releases

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through the Culebra (Section 2.8) adds release points to the west of the current repository to account for possible westward movement of radionuclides. These PA changes do not affect existing FEPs screening decisions nor do they represent changes to PA conceptual models. Therefore, a FEPs assessment and a conceptual model review are not planned for the RPPA.

2.2 Inventory

A new PAIR will be issued based on the 2021 Annual Transuranic Waste Inventory Report. The new inventory will be used in the RPPA calculation. The PAIR will contain updated estimates to the radionuclide content and waste material parameters, scaled to a full repository. To incorporate these changes, the initial radionuclide, chemical components, and waste material inventories will be updated. Parameters which are calculated based on the initial radionuclide inventories, such as the Waste Unit Factor (WUF) and the initial lumped radionuclide inventories, will be updated as well.

2.3 Updates to Radionuclide Solubilities

The solubilities of actinide elements are influenced by the chemical components of the waste and the amount of halite available for reaction. With the new PAIR, updated information on the amount of various chemical components in the waste is available. With the increased repository volume, the DRZ volume providing halite to the system will also be increased. To incorporate this updated information, parameters used to represent actinide solubilities will be updated in the RPPA.

Radionuclide solubilities are calculated at 5 integer multiples of the minimum brine volume needed for a DBR event (GLOBAL:DBRMINBV). With the additional repository volume, the minimum brine volume for a DBR event will be updated (King, 2021c). In calculating the radionuclide mobilization, the PANEL code uses the minimum brine volume needed for a DBR event.

The CRA-2019 PA used the DATA0.FM4 database for actinide baseline solubilities, but it was later realized that incorrect thermodynamic interaction parameter values resulted in lower actinide (III) baseline solubility values. Analysis showed that correcting the actinide (III) baseline solubility values had no impact on the CCDF of total releases (Kim et al., 2020). The APPA analysis used the DATA0.FM5 thermodynamic database (Domski, 2020) with corrected thermodynamic interaction parameter values. During the completeness review of CRA-2019, additional questions were raised about DATA0.FM4 database. Resolution of these questions may lead to additional changes to the thermodynamic database before calculating actinide baseline solubilities for the RPPA.

2.4 Sample of Uncertain Parameters

For the RPPA, no changes are planned that affect parameters considered to be uncertain. Consequently, the APPA will use the same parameter sample as was generated for the APPA and the CRA-2019.

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2.5 Salado Flow

The RPPA uses the same conceptual and mathematical models for Salado flow as were used for the APPA, which in turn were based on the conceptual and mathematical models for the CRA-2019. Numerical calculations will be done with the BRAGFLO 7.00 code on a revised grid that accounts for the new panels.

2.5.1 BRAGFLO Grid

In the CRA-2019 (DOE, 2019, Appendix PA) the repository is modeled as comprising ten waste panels with emplaced waste and additional excavated volumes without waste. Other significant repository features represented in the PA include the panel closures and shafts. Figure 2 displays the computational grid used by the BRAGFLO model to calculate brine and gas flow in the Salado, showing each represented feature.

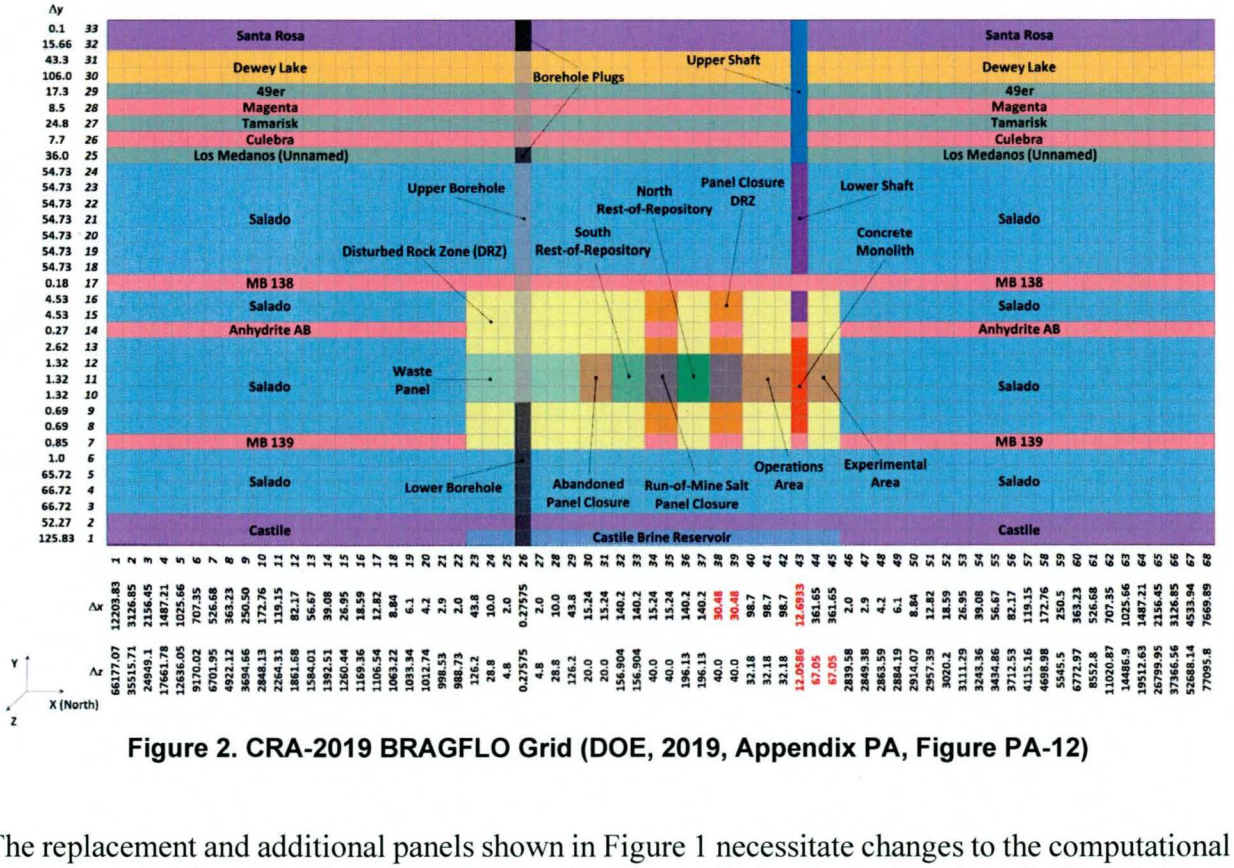

Figure 2. CRA-2019 BRAGFLO Grid (DOE, 2019, Appendix PA, Figure PA-12)

The replacement and additional panels shown in Figure 1 necessitate changes to the computational grid shown in Figure 2. The BRAGFLO model uses a 2D (north-south and vertical) grid that is flared in the east-west direction to account for volumes. This 2D approach enables significant simplifications to the mathematical and numerical models for Salado flow and has been determined to be adequate and reasonable for WIPP PA (Caporuscio et al., 2003; Falta et al., 2021). Two-dimensional flaring is used where the flows of primary interest are converging (or diverging), as is the case in the WIPP PA with flows through excavated areas towards boreholes.

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With the western panels, the repository floor plan assumes an "L" shape rather than the generally linear, north-south geometry in the current repository floor plan. To represent this geometry in a 2D grid, the L shape is unbent to a linear arrangement of panel groups as depicted in Figure 3. Consistent with the Salado Formation's general regional dip to the south-east (Appendix GCR, 1978), a 1% dip from north to south (right to left in Figure 3) is applied to the linear grid.

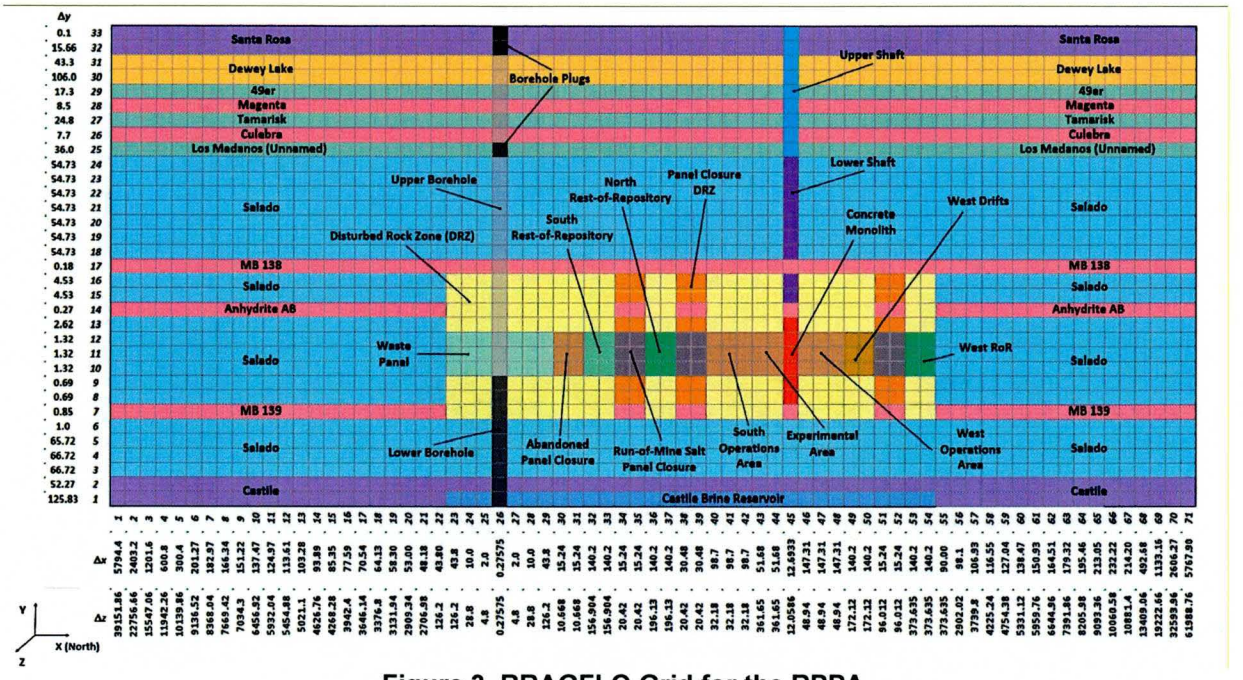

Figure 3. BRAGFLO Grid for the RPPA

The grid in Figure 3 implements rectangular flaring at two scales: locally around the borehole and regionally to the north and south of the excavated region. The local flaring around the borehole is unchanged from the CRA-2019. The center of regional flaring is moved from the center of the panel closure dividing North Rest-of-Repository from South Rest-of-Repository in Figure 2, to a point at the center of the experimental area in Figure 3, to balance the excavated volumes to the left and right of the regional flaring center. Grid cell dimensions in the Δx direction are adjusted near the excavated region to improve the transition between the local and regional flaring.

The Land Withdraw Boundary (LWB) to the south of the repository is located in the RPPA grid between columns 4 and 5; the distance between the Waste Panel and the LWB has not changed from the CRA-2019 grid. On the right side of the RPPA grid, the LWB is located between columns 67 and 68 at the distance between the proposed west waste panels and the western LWB. The distance between the LWB and the grid domain boundary has been reduced from 20 km in the CRA-2019 grid to 10 km in the RPPA grid.

The BRAGFLO grid (Figure 3) aggregates waste panels into four waste-bearing areas denoted South Waste Panel (WAS), South Rest of Repository (SRR), North Rest of Repository (NRR), and West Rest of Repository (WRR). Table 1 lists the panels which comprise each waste-bearing area in the BRAGFLO grid. One representative borehole is placed in the grid in the South Waste Panel area. The borehole in the South Waste Panel is considered to be a conservative representation of

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an intrusion into any waste panel, as the South Waste Panel tends to have higher saturation, being downdip from other panels.

Table 1. Panel Groups in the RPPA

Panel Group	Repository Section	Panels in Panel Group
South Waste Panel (WAS)	South	5
South Rest of Repository (SRR)	South	3, 4, 6, 9
North Rest of Repository (NRR)	South	1, 2, 7, 8, 10
West Rest of Repository (WRR)	West	11, 12, 13, 14, 15, 16, 17, 18, 19

The DOE no longer plans to emplace waste in Panel 9. However, as was done in the CRA-2019, the RPPA will model Panel 9 as containing waste to simplify the modeling. The RPPA waste inventory will be represented as homogeneous over the volume of the repository; the repository volume (parameter REFCON:VREPOS) will be the volume of 19 waste panels. This treatment of Panel 9 has been shown to be conservative with respect to releases from the repository (Zeitler et al., 2017). Modeling Panel 9 as having waste places a proportionally greater volume of emplaced waste downdip and in a waste area adjacent to the South Waste Panel, which contains the representative borehole.

The operations area maintains its dimensions as in the CRA-2019 grid but is renamed here as the South Operations area. The volume of the experimental area changes from the CRA-2019 grid. In the CRA-2019, the volume of the additional shaft access drifts is included in the experimental area (Day, 2019). Here, a new West Operations area incorporates all drifts to the new panels and the additional shaft access drifts (Figure 1). Compared to the CRA-2019 grid, the x- and z-dimensions of the experimental area are swapped so that the experimental area offers little impedance to flow between the west and south areas of the repository, while maintaining the experimental area's excavated volume.

As in the CRA-2019, the planned fifth shaft will be combined with the four existing shafts into a single shaft feature in the BRAGFLO grid for the RPPA. The SHFT14 analysis (Camphouse, 2014) showed minimum impact to the long-term repository performance from representing the additional shaft in this manner.

For the APPA, the major assumptions used in the BRAGFLO grid for the Salado flow model (Figure 3) were reviewed by the APPA Changed Conceptual Models Peer Review. The peer review panel found the assumptions to be well justified and the model adequate and reasonable for its intended application (Falta et al., 2021).

The RPPA Salado Flow grid (Figure 3) is the same as the grid used for the APPA, except for one correction to the shaft dimensions. In the APPA the shaft was mistakenly given the dimensions 17.1194 m by 17.6197 m. In the RPPA grid, the shaft dimensions are corrected to 12.6933 m by 12.0586 m giving a cross sectional area of 153.06 m^2 as specified by Zeitler (2019). Due to the correction to the shaft dimensions, the far-field Salado flaring is updated using the same methodology as was used to set the APPA grid flaring.

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2.5.2 Iron Surface Area

For CRA-2019 and the APPA, the total surface area of iron-based metals for gas generation was calculated based on an estimated iron surface per drum, and an optimal loading of drums in the repository. For the RPPA, the total iron surface area will be calculated with an estimated surface area per kilogram of iron inventory (REFCON:FESAPKG), as outlined in King (2021a). With this new parameter, the REFCON:ASDRUM, REFCON:DRROOM, and REFCON:VROOM parameters will not be used in the RPPA.

2.5.3 Initial Pressure

In CRA-2019, the pressure in the waste areas at repository closure was set to 128,039 Pa. The 26,714 Pa increase over atmospheric pressure is to account for the early-time rapid biodegradation of cellulose, plastic, and rubber (CPR). The pressure increase is a function of CPR inventory and repository volume as calculated by Nemer et al. (2005). For the APPA the initial pressure was set at 115,610 Pa, which is less than in the CRA-2019 due to the additional storage volume. However changes to the CPR inventory since the Nemer et al. (2005) calculation were not incorporated. To facilitate setting of the initial pressure parameter, a new parameter (WAS_AREA:EGRATMIC) for the moles of gas generated per kilogram of CPR inventory has been defined (King, 2021b). This parameter will be used in the Salado flow ALGEBRACDB step to calculate the initial waste area pressure.

2.5.4 Scenarios for Salado Flow Modeling

The Salado flow model computes two-phase (brine and gas) spatially- and temporally-varying pressure, saturation, and flow in both undisturbed and disturbed conditions. Disturbed conditions are modeled by imposing a borehole representing a drilling intrusion in the BRAGFLO grid. Table 2 lists the intrusion scenarios and their characteristics; the intrusion scenarios for the RPPA are unchanged from the APPA and the CRA-2019.

Table 2. Intrusion Scenarios for the Replacement Panel PA

Scenario	Description
E0	Undisturbed repository
E1	Drilling intrusion that intersects a brine reservoir in the Castile
E2	Drilling intrusion that does not intersect a brine reservoir in the Castile
E1E2	Multiple intrusions into the same waste panel with at least one E1 intrusion

For the RPPA a representative borehole is placed in the south half of the repository as indicated in Figure 3. The BRAGFLO scenarios for the RPPA are unchanged from the APPA and the CRA-2019 as indicated in Table 3.

Table 3. BRAGFLO Modeling Scenarios for the Replacement Panel PA

Scenario	Description
S1-BF	Undisturbed repository
S2-BF	E1 intrusion at 350 years in South Waste Panel
S3-BF	E1 intrusion at 1,000 years in South Waste Panel

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Scenario	Description
S4-BF	E2 intrusion at 350 years in South Waste Panel
S5-BF	E2 intrusion at 1,000 years in South Waste Panel
S6-BF	E2 intrusion at 1,000 years; E1 intrusion at 2,000 years in South Waste Panel

2.6 Salado Transport

Models to estimate transport in the Salado are implemented in the PANEL and NUTS codes. The PANEL code simulates radionuclide decay and mobilization in brine, resulting in time-dependent mobilized concentrations in the waste panels. The NUTS code simulates radionuclide decay and advective transport in the Salado formation for the E0, E1, and E2 scenarios using the same 2D grid as BRAGFLO. A second usage of PANEL is to compute radionuclide transport to the Culebra in the E1E2 intrusion scenario.

2.6.1 Radionuclide Mobilization

The PANEL code calculates mobilized radionuclide concentration as the sum of the dissolved and colloidal contributions for 13 elements (Am, Cf, Cm, Cs, Np, Pa, Pb, Pm, Pu, Ra, Sr, Th and U) and their isotopes inside the waste panels during the 10,000-year regulatory period. Except as noted in section 2.3, these calculations are the same in the RPPA as in the APPA and CRA-2019.

2.6.2 Models for Salado Transport

The models for Salado transport for the RPPA are the same as for the APPA and for the CRA-2019 (DOE, 2019, Appendix PA).

The NUTS code simulates advective transport of radionuclides in the Salado for the E0, E1 and E2 intrusion scenarios, using the 2D BRAGFLO grid (Figure 3 for the RPPA). NUTS takes as input inventories of 5 lumped radionuclides, effective solubility limits (mobilized concentrations in the absence of inventory limits) calculated by PANEL, and transient brine flow fields calculated by BRAGFLO. It returns radionuclide mass fluxes which are summed to calculate cumulative radionuclide release up the shafts or boreholes to the Culebra and through the marker beds to the land withdrawal boundary. Transport calculations are performed with intrusion times of 350 and 1000 years (in Table 3) as well as other intrusion times (100, 3000, 5000, 7000 and 9000 years).

The PANEL code is used to calculate cumulative radionuclide release through a borehole to the Culebra for the E1E2 scenario. This scenario assumes a sequence of two intrusions: an E2 followed by an E1 intrusion that admits Castile brine to the repository. To calculate cumulative radionuclide release, PANEL integrates the product of brine flow rate from the BRAGFLO S6-BF scenario and time-dependent mobilized radionuclide concentration. Transport calculations are performed with E1 intrusion times of 100, 350, 1000, 2000, 4000, 6000, and 9000 years. The PANEL code internally shifts brine flow times from BRAGFLO S6-BF scenario (E1 intrusion at 2000 years) to get brine flows for other E1 intrusion times.

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2.7 Direct Releases

Direct releases of radionuclides to the surface following a drilling intrusion include direct brine releases (DBRs), spallings, cuttings, and cavings. Direct releases are calculated by models for each process applied to several direct release scenarios that vary with time of intrusion, intrusion location relative to previous intrusions, and the type of previous intrusions. For the RPPA, direct releases are calculated using the same models as for the APPA.

2.7.1 Direct Brine Release

In the CRA-2019, DBR volumes were calculated for the scenarios listed in Table 4 using the BRAGFLO_DBR code on a horizontal grid (Figure 4) at each of three representative boreholes: Lower (L), Middle (M), and Upper (U). The Lower intrusion was modeled as occurring in Panel 5 and represents a subsequent intrusion into the same panel as the previous intrusion (all previous intrusions are modeled as occurring in panel 5, as indicated in Figure 4). The Middle intrusion was modeled as occurring in Panel 3 and represents a subsequent intrusion into a panel adjacent (i.e., no intervening panel closure) to a panel with a previous intrusion. The Upper intrusion was modeled as occurring in Panel 10 and represents a subsequent intrusion into a panel with no previous intrusions in its adjacent panels, but with previous intrusions into non-adjacent panels (i.e., with intervening panel closures). A full description of the approach to calculating DBR volumes is provided in Bethune (2019).

Table 4. Direct Brine Release Scenarios in the CRA-2019

Scenario	Previous Intrusion Type and Time	DBR Intrusion Times (yr)
S1-DBR	None	100, 350, 1000, 3000, 5000, 10000
S2-DBR	E1 intrusion at 350 yr (S2-BF)	550, 750, 2000, 4000, 10000
S3-DBR	E1 intrusion at 1000 yr (S3-BF)	1200, 1400, 3000, 5000, 10000
S4-DBR	E2 intrusion at 350 yr (S4-BF)	550, 750, 2000, 4000, 10000
S5-DBR	E2 intrusion at 1000 yr (S5-BF)	1200, 1400, 3000, 5000, 10000

For the RPPA, the direct brine release conceptual models are unchanged from the CRA-2019 (DOE, 2019, Appendix PA) and the DBR scenarios will be the same as the CRA-2019 (as listed in Table 4). The grid for calculating direct brine releases (Figure 5) is adjusted to create a new panel group with a new representative borehole that is used to estimate DBR volumes from intrusions into the proposed additional waste panels. The DBR grid for the RPPA retains the 10 notional "panels," termed here DBR panels, used in the CRA-2019 (Figure 4) but the interpretation of each DBR panel is different in the RPPA (Figure 5).

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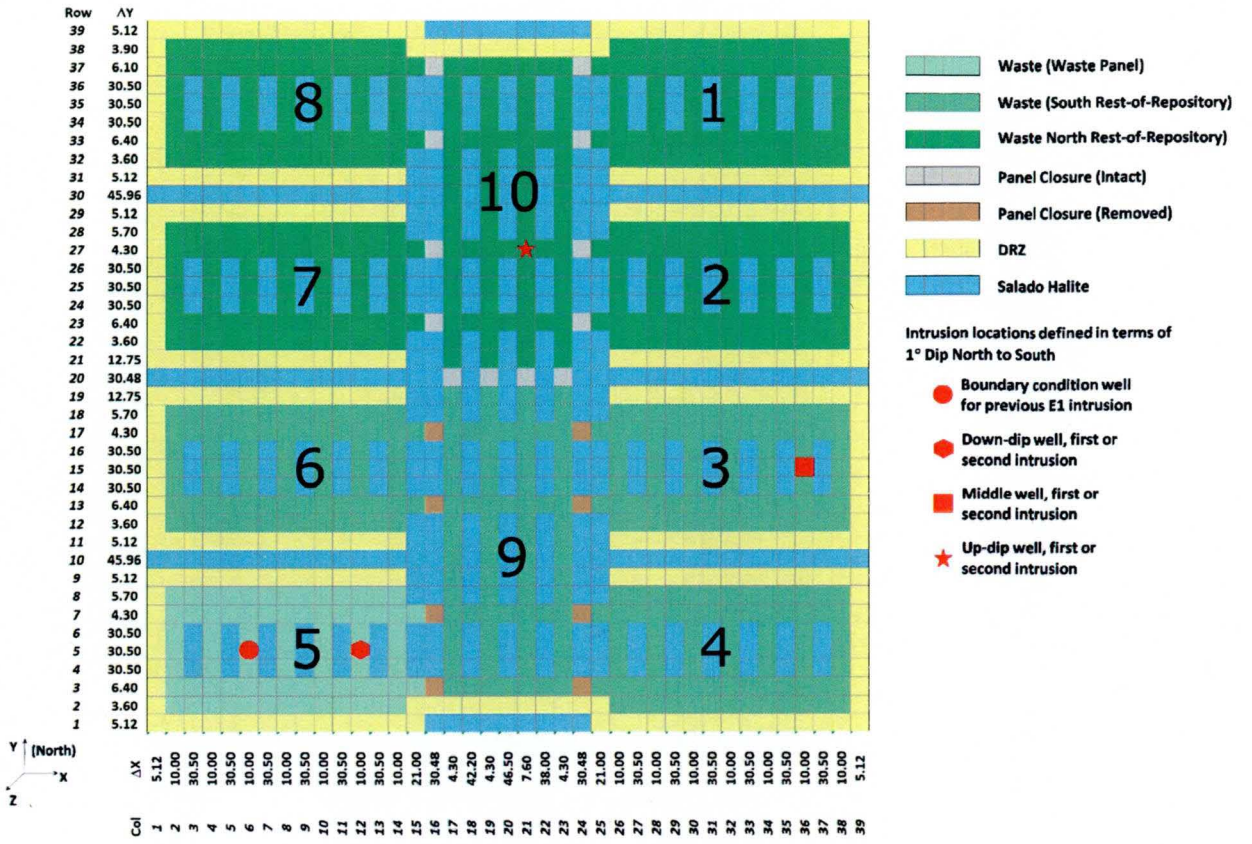

Figure 4. BRAGFLO_DBR Grid for the CRA-2019

Initial conditions for a DBR panel (Figure 5) are taken from the panel groups in the BRAGFLO grid (Figure 3), and releases are separately calculated for four representative boreholes (lower, middle, upper and other, Figure 5):

- The lower (L) borehole is located in DBR Panel 5 and initial conditions for the DBR panel containing this borehole are taken from the South Waste Panel (WAS) region of the BRAGFLO grid.
- The middle (M) borehole is located in DBR Panel 3 and initial conditions for the group of DBR panels containing this borehole (comprising DBR Panels 3, 4, 6 and 9) are taken from the South Rest of Repository (SRR) region of the BRAGFLO grid.
- The upper (U) borehole is located in Panel 2 and initial conditions for the group of DBR panels containing this borehole (comprising DBR Panels 2, 7 and the south half of DBR Panel 10) are taken from the North Rest of Repository (NRR) region of the BRAGFLO grid.
- The other (O) borehole is located in DBR Panel 1 and initial conditions for the group of DBR panels containing this borehole (comprising DBR Panels 1, 8 and the north half of DBR Panel 10) are taken from the West Rest of Repository (WRR) region of the BRAGFLO grid.

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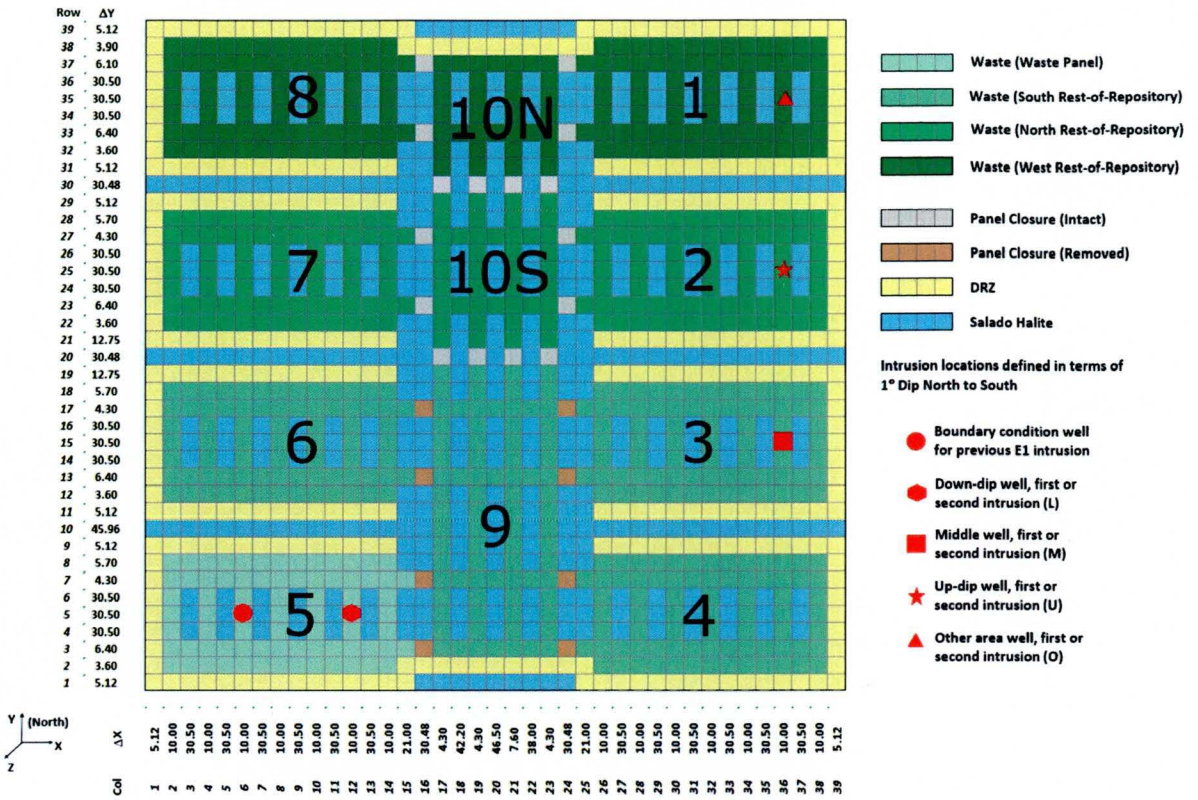

Figure 5. BRAGFLO_DBR Grid for the Replacement Panels PA

Analyses have shown that direct brine release volumes are primarily determined by the conditions in the intruded panel; other areas in the DBR grid have little to no effect on DBRs (Shumaker, 2021). Thus, DBRs resulting from boreholes in the waste panels comprising the NRR or WRR can be reasonably represented by the DBRs from an intrusion into e.g., Panel 1, since the waste panel volumes are similar. The assumptions and DBR model were reviewed by the APPA peer review panel. The peer review panel found the assumptions used to be justified, and the DBR model was found to be adequate and reasonable for its intended purpose (Falta et al., 2021).

2.7.2 Representative Boreholes for Direct Brine Releases

DBRs from an intrusion into the repository are modeled by results of the DBR scenarios (Table 4); and the representative borehole for an intrusion is determined as shown in Table 5. The representative borehole for a DBR from an intrusion into the repository with undisturbed conditions is determined by the intruded panel. After the initial intrusion, DBRs for a subsequent intrusion are based on the distance between the panel containing the subsequent intrusion and the nearest panel with a previous E1 intrusion. If no previous E1 intrusion has occurred, releases are determined by the nearest panel with an E2 intrusion. The distances between panels are specified by the panel groups indicated in Table 6, in order of nearest to farthest, Same, Connected, Adjacent and Non-adjacent. The representative borehole associated with each distance is identified in Table 5.

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Table 5. 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 – 19	Non-adjacent

2.7.3 Panel Groups and Neighbors

The CRA-2019 classified panels into one of three groups as determined by the number of panel closures separating each waste panel from Panel 5: same, adjacent, and non-adjacent (Brunell, 2019).

For the RPPA the panel neighbor groups are extended to same, connected, adjacent, and non-adjacent which requires a change from CCDFGF v7.05. Two panels are connected if there are no intervening panel closures, e.g., Panels 4 and 5 are connected. Two panels are adjacent if both panels are in the same half of the repository (i.e., south or west) but are separated by one or more intervening panel closure, e.g., Panels 1 and 5 are adjacent. Two panels are non-adjacent if the panels are in different halves of the repository, e.g., Panels 1 and 11 are non-adjacent. The path between panels is traced through excavated areas only. The panel neighboring is the same as in the APPA.

As discussed in Section 2.7.2 and, the panels are grouped according to their relative location within the repository for the purposes of interpolating releases from calculations for specific DBR scenarios. The lower panel group comprises Panel 5. Conditions in the lower panel group are used to estimate releases from an intrusion into a previously intruded panel. The middle group comprises Panels 3, 4, 6, and 9; conditions in this panel group are used to estimate releases from intrusions into a panel that has no previous intrusion but is not separated by a panel closure from a panel with a previous intrusion. The upper panel group comprises Panels 1, 2, 7, 8 and 10. Conditions in the upper panel group are used to calculate releases from an intrusion into a panel that has no previous intrusions, no connected panel has a previous intrusion, and previous intrusions have occurred in adjacent panels. The other panel group comprises the proposed new waste panels numbered 11 through 19. Conditions in the other panel group are used to estimate releases from an intrusion into a panel without a previous intrusion, and that is in a different half of the repository than all panels with previous intrusions (i.e., the south section vs. the west section).

The CCDFGF code simulates random sequences of drilling intrusions. Each intrusion is placed in one of the waste panels using the probabilities listed in Table 6. When a new intrusion occurs, previous intrusions in the same, connected, and adjacent panels determine the conditions for calculating releases from the new intrusion; Table 6 summarizes the panel neighbor scheme for the RPPA. Panels not designated as same, connected, or adjacent are defined as non-adjacent.

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Table 6. Panel Neighbors in the RPPA

Intruded Panel	Intrusion Probability	Connected Panels	Adjacent Panels
1	0.053662264	-	2 through 10
2	0.053662264	-	1, 3 through 10
3	0.053662264	4, 5, 6, 9	1, 2, 7, 8, 10
4	0.053662264	3, 5, 6, 9	1, 2, 7, 8, 10
5	0.053662264	3, 4, 6, 9	1, 2, 7, 8, 10
6	0.053662264	3, 4, 5, 9	1, 2, 7, 8, 10
7	0.053662264	-	1 – 6, 8, 9, 10
8	0.053662264	-	1 – 7, 9, 10
9	0.042154636	3, 4, 5, 6	1, 2, 7, 8, 10
10	0.045586876	-	1 through 9
11	0.053662264	-	12 – 19
12	0.053662264	-	11, 13 – 19
13	0.053662264	-	11 – 12, 14 – 19
14	0.053662264	-	11 – 13, 15 – 19
15	0.053662264	-	11 – 14, 16 – 19
16	0.053662264	-	11 – 15, 17 – 19
17	0.053662264	-	11 – 16, 18 – 19
18	0.053662264	-	11 – 17, 19
19	0.053662264	-	11 – 18

2.7.4 Spallings

Spalling releases are calculated by combining a spalling volume obtained by interpolation on a table of single borehole spalling volumes with a time-dependent radionuclide concentration in the solid waste calculated by the code PANEL. The RPPA will use the table of single borehole spallings volumes from the CRA-2019 as none of the changes since the CRA-2019 affect the calculation of these volumes. The spalling release volume for an intrusion is determined by interpolating the table to the pressure in the intruded panel at the intrusion time. The panel conditions for spallings are determined using the scenarios for DBR release volumes. The DBR release scenario is determined by the borehole location and the type and distance to any previous intrusions as described in Section 2.5.3. The pressure in the intruded panel is estimated by interpolating the initial conditions for DBR releases to the intrusion time using the DBR calculation cases listed in Table 4.

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2.7.5 Cuttings and Cavings

For the RPPA, cutting and cavings releases will be estimated using the CRA-2019 models with no changes (DOE, 2019, Appendix PA). If the borehole intersects contact-handled waste, cuttings and cavings release volumes are calculated by multiplying the eroded borehole diameter by the repository height; cuttings and cavings releases are then calculated by multiplying 1/3 of the release volume with the time-dependent radionuclide concentration (calculated by the code PANEL) in each of three randomly selected CH-waste streams. The probability of selecting a waste stream is equal to the waste stream's volume fraction in the inventory.

If the borehole intersects remote-handled waste, cuttings and cavings release volumes are calculated by multiplying the eroded borehole diameter by the remote handled waste height of 0.509 m (Parameter REFCON:HRH). Cuttings and cavings releases are then calculated by multiplying the release volume with the time-dependent radionuclide concentration in a randomly selected RH-waste stream.

2.8 Culebra Flow and Transport

Radionuclides may be transported to the Culebra via boreholes or through the shaft. Models and codes for transport to the Culebra are the same as in the CRA-2019. The Culebra flow and transport calculations from the CRA-2009 PABC were used in the CRA-2014 PA and the CRA-2019 PA, and are fully described in the CRA-2009 PABC analysis package for radionuclide transport in the Culebra Dolomite (Kuhlman, 2010). In each transport simulation, 1 kg of each of ^{241}Am, ^{239}Pu, ^{234}U, and ^{229}Th was released at a single point during the first 50 years after repository closure.

The proposed new panels necessitate a change to the location of the modeled releases into the Culebra. In the CRA-2019 and the APPA, releases into the Culebra are modeled to occur above the centroid of the waste panels in the existing repository. The predominant regional flow in the Culebra is to the south. However, the proposed new panels extend westward into areas affected by potash mining in the full-mining scenario, where enhanced transmissivity can draw flow toward the western delineation of the land withdrawal boundary.

For the RPPA, Culebra transport calculations will include releases into the Culebra at three additional locations to account for the potential for westward transport above the new panels (Figure 6). Kushnereit et al. (2020) calculated the particle tracks of a conservative tracer released into the Culebra at points distributed across the western repository region for partial and full mining flow fields from the CRA-2019. The particle tracking analysis is used to define groups of waste panels with similar particle transport direction, travel distance and travel time. For each group a release point is located in the Culebra at the centroid of the group's panels.

Four panel groups were identified (Bethune and Brunell, 2022):

- Group 1 comprises Panels 1 through 10. Discharge to the Culebra from boreholes in Panels 1 through 10 or through the shafts will be modeled with a release point near the centroid of the existing repository, as was done for CRA-2019. The release point for Group 1 is labeled CRP 1.
- Group 2 is composed of Panels 11, 12, and 13, which are characterized by particle tracks with predominately southward flow and shorter travel distances and times to the land

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withdrawal boundary relative to Group 3. The release point for Group 2 panels is labeled CRP 2.

- Group 3 is composed of Panels 14 and 19, which are characterized by having particle tracks that predominately flow to the south and east, but with longer travel distances and times to the land withdrawal boundary relative to Group 2. The release point for Group 3 panels is labeled CRP 3.
- Group 4 is composed of Panels 15, 16, 17, and 18, which are characterized by having a relatively high percentage of particle tracks that exit the western land withdrawal boundary in the full-mining scenario. Waste panels in Group 4 are all at least partially inside the full-mining region. The release point for Group 4 panels is labeled CRP 4.

Aside from the new release locations, Culebra flow and transport will be calculated using the same procedure described in the CRA-2009 PABC analysis package for radionuclide transport in the Culebra Dolomite (Kuhlman, 2010).

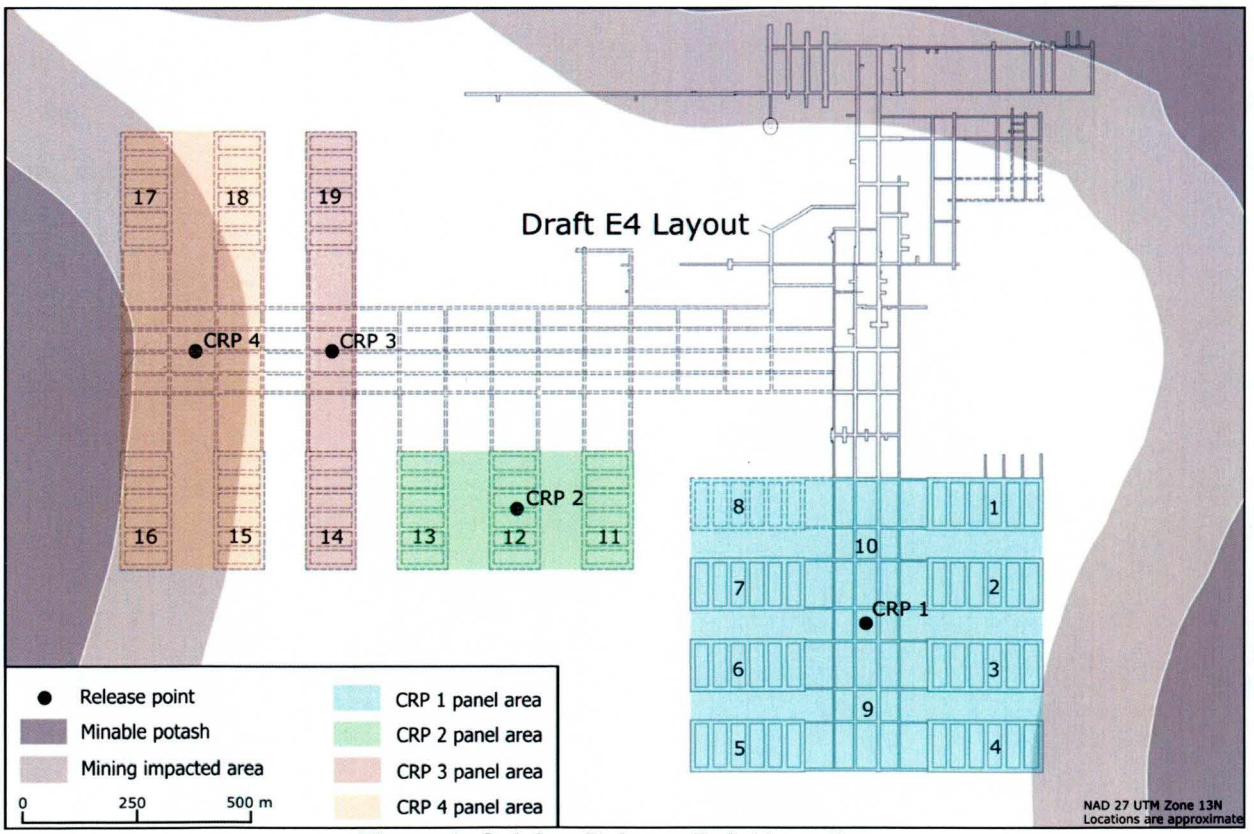

Figure 6. Culebra Release Point Locations

2.9 Calculation of CCDFs for Releases

The conceptual structure of the RPPA remains the same as for the CRA-2019. For each element in a sample of uncertain parameters, many 10,000-yr futures are randomly generated. Each future comprises a sequence of simulated drilling and mining intrusions. For each intrusion, direct releases are tabulated using output from the models described above, and over the course of the entire future, releases through the Salado and Culebra to the land withdrawal boundary are

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recorded using output from the Salado and Culebra transport models. The total of these various releases at the end of the 10,000-yr period yields one data point for total releases; the collection of total release data points over all futures comprises the data that forms one complementary cumulative distribution function (CCDF) of releases. The code CCDFGF generates the random futures and estimates the CCDFs. A formal definition of this conceptual structure is found in Appendix PA of DOE, 2019.

For the CRA-2019, PRECCDFGF v 2.01 and CCDFGF v 7.03 were used. For the APPA, PRECCDFGF was modified to v2.02 and CCDFGF was modified to v.7.05 to accept results for four representative boreholes (Section 2.7.2) and to extend the panel adjacency relationships (Section 2.7.3). Both codes will also be modified for the RPPA calculation to accumulate results for multiple release points into the Culebra (Section 2.8).

2.10 Culebra Travel Times

Particle travel times in the Culebra from each release point to the LWB will be calculated with the DTRKMF code for the no-mining, full-mining, and partial-mining scenarios. Travel times will be used in sensitivity analyses to quantify the importance of the T-field selection to uncertainty in analysis outputs. If travel times are highly correlated among release points, travel times for one release point will be retained in the sensitivity analysis while the others will be dropped. The GLOBAL:TRANSIDX parameter will be used to associate travel times with each vector. The GLOBAL:TRANSIDX parameter will be excluded from the sensitivity analysis because, being an index, TRANSIDX should have no monotonic relationship to releases.

2.11 Sensitivity Analysis

The RPPA will include sensitivity analyses to quantify the influence of uncertain parameters on the uncertainty in select outputs from the PA models, to include:

- Pressure and saturation in the excavated areas.
- Brine flow in the borehole.
- Releases by cuttings, cavings, spallings, direct brine release and by Salado and Culebra transport.
- Total releases.

The sensitivity analysis will be done using the code STEPWISE.

3 Parameters

Several parameters related to repository areas and volumes will be updated for the RPPA to account for the proposed new panels, including:

- REFCON:ABERM – Area of the berm placed over waste panels.
- REFCON:AREA_CH – Area for contact-handled (CH) waste disposal.
- REFCON:FVW – Fraction of the repository volume occupied by waste.
- REFCON:VREPOS – Excavated storage volume of the repository.
- CAVITY1:PRESSURE – Brine pressure in the waste panel at repository closure.
- CAVITY2:PRESSURE – Brine pressure in the rest-of-repository at repository closure.

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- GLOBAL:DBRMINBV – Minimum volume of brine in the repository required for a direct brine release.

Additionally, several new parameters will be defined and used in the RPPA:

- WAS_AREA:EGRATMIC – Moles of gas generated per kilogram of cellulose from early-time rapid CPR biodegradation.
- REFCON:FESAPKG – Iron surface area per kilogram of iron inventory.

Parameters relating to the updated radionuclide inventory and baseline actinide solubilities will be updated. Updates to parameters will follow Nuclear Waste Management Procedure NP 9-2, Parameters.

4 Reports and Documentation

Several reports will be generated as a result of this analysis plan. Each set of calculations discussed in Section 2 for the RPPA analysis will be documented in an analysis report. These reports will include:

1. discussion of any implementation changes (parameters, modeling assumptions, etc.) relative to the corresponding CRA-2019 PA calculations; and
2. analysis of results relevant to the long-term performance of the repository. The analysis will include comparisons of RPPA analysis results with the CRA-2019 PA.

A record of the run control will be created for the RPPA. This document will contain:

1. A description of the hardware platform and operating system used to perform the calculations.
2. A listing of the codes and versions used to perform the calculations.
3. A listing of the scripts used to run each calculation.
4. A listing of the input and output files for each calculation.
5. A listing of the library or file directory where each file is stored.
6. File naming conventions.

Additional analyses, calculations, and documentation performed as part of the regulatory review and approval process for the RPPA will also fall under AP-193.

5 Tasks

The tasks, responsible personnel, and estimated task schedule are summarized below in Table 7.

Table 7: Task List and Estimated Schedule for the RPPA

Task	Description	Guiding Document	Approximate Completion Date	Responsible Individual(s)
1	PRECCDFGF Code Modifications	AP-193	2/28/2022	Brunell
2	CCDFGF Code Modifications	AP-193	2/28/2022	Brunell
3	Inventory Analysis Report	AP-193	3/28/2022	Kicker

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Task	Description	Guiding Document	Approximate Completion Date	Responsible Individual(s)
4	Input Files Prepared	AP-193	4/11/2022	Bethune, Brunell, Kicker, Kim, King, and Zeitler
5	Input File Review	AP-193	4/25/2022	Hansen
6	Parameter Data Entry and QA Review	NP 9-2	5/31/2022	Long
7	SECOTP2D Calculations	AP-193	2/3/2022	Long
8	Main PA Calculations	AP-193	6/7/2022	Long
9	Analysis Reports	NP 9-1	9/29/2022	Hansen
9a	Salado Flow: BRAGFLO	AP-193	9/8/2022	King
9b	Actinide Mobilization and Salado Transport: NUTS & PANEL	AP-193	9/8/2022	Kim
9d	Culebra Flow and Transport: MODFLOW and SECOTP	AP-193	9/8/2022	Bethune
9d	Direct Brine Release: BRAGFLO_DBR	AP-193	9/8/2022	King
9e	Run Control Document	AP-193	9/8/2022	Long
10	Summary Report, including parameter updates, direct releases, CCDFs for normalized releases, and sensitivity analysis	AP-193	9/29/2022	Bethune, Brunell, Hansen, Kicker, Kim, King, Long, Zeitler

6 Software

The major WIPP PA codes to be used for this analysis are listed in Table 8. The execution of these codes for the analysis described herein comprises a compliance decision calculation. These codes will be executed on the WIPP PA Sun Blade Cluster, which is described in Table 9. Additionally, we may utilize COTS (commercial off-the-shelf) software such as Matlab®, Sigma Plot®, Excel®, Access®, or Python, running on individual workstations. The use of any COTS application will be verified per NP 9-1 Appendix C as appropriate.

DRSPALL v1.22 and MERGESPALL v1.01 will not be run for the RPPA. Instead, output results from a previous analysis (Kirchner et al., 2014; Kirchner et al., 2015) will be used as input to the RPPA calculations. The inputs to these codes are the same for the RPPA as for the previous analysis.

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Table 8. Codes to be Used for the RPPA

Code	Version	Executable	Build Date
ALGEBRACDB	2.36	algebracdb	9/11/12
BRAGFLO	7.00	Bragflo	8/14/18
CCDFGF	8.00	Ccdfgf	TBD*
CCDFVECTORSTATS	1.01	ccdfvectorstats	3/20/18
CUTTINGS_S	6.03	cuttings_s	1/15/13
DTRKMF	1.01	dtrkmf	7/14/14
EPAUNI	1.19	epauni	9/12/16
GENMESH	6.10	genmesh	1/12/15
ICSET	2.23	icset	9/11/12
LHS	2.44	lhs	6/2/15
MATSET	9.24	matset	10/11/16
NUTS	2.07	nuts	2/22/19
PANEL	5.00	panel	2/18/19
POSTBRAG	4.02	postbrag	1/10/13
POSTSECOTP2D	1.05	postsecotp2d	4/18/13
POSTLHS	4.11	postlhs	6/2/16
PREBRAG	9.00	prebrag	8/16/18
PRECCDFGF	3.00	preccdfgf	TBD*
PRESECOTP2D	1.23	presecotp2d	4/8/13
PRELHS	2.44	prelhs	10/11/16
RELATE	1.45	relate	9/11/12
SCREEN_NUTS	1.02	screen_nuts	2/7/18
SECOTP2D	1.43	secotp2d	8/2/2013
STEPWISE	2.22	stepwise	7/2/13
SUMMARIZE	3.02	summarize	10/31/12

*- CCDFGF version 7.05 and PRECCDFGF version 2.02 are currently the baseline versions of the codes. Changes to both codes are needed for the RPPA.

Table 9. WIPP PA Solaris Cluster Compute Nodes

Node	Hardware Type	CPU	Operating System	# CPUs
BEP	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
BLS	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
DC5	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24

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Node	Hardware Type	CPU	Operating System	# CPUs
GD	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
GFD	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
IRON	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
LZ	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
PF	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
VH	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
ZP	Oracle/SUN X6270 m2	x86 (GenuineIntel 206C2 family 6 model 44 step 2 clock 3458 MHz)	Oracle Solaris 11	24
BC	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
BOS	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
CHI	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
FOG	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
HP	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
JA	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
ML	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
RE	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
UH	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
ZZ	Oracle/SUN X4-2B	x86 (GenuineIntel 306E4 family 6 model 62 step 4 clock 2693 MHz)	Oracle Solaris 11	48
SAN	Dell PowerEdge R820	x86 (GenuineIntel 206D7 family 6 model 45 step 7 clock 2400 MHz)	Oracle Solaris 11	64

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7 Special Considerations

None.

8 Applicable Procedures

All applicable WIPP QA procedures will be followed when conducting these analyses.

- Training of personnel will be conducted in accordance with the requirements of NP 2-1, *Qualification and Training*.
- FEPs assessment will be conducted according to SP 9-4, *Performing FEPs Impact Assessment for Planned or Unplanned Changes*.
- Analyses will be conducted and documented in accordance with the requirements of NP 9-1, *Analyses*.
- All software used will meet the requirements laid out in NP 19-1, *Software Requirements* and NP 9-1, as applicable.
- The analyses will be reviewed following NP 6-1, *Document Review Process*.
- All required records will be submitted to the WIPP Records Center in accordance with NP 17-1, *Records*.
- New and revised parameters will be created as discussed in NP 9-2, *Parameters*.

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