SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

Summary Report for the NEPA Analysis

Revision 1

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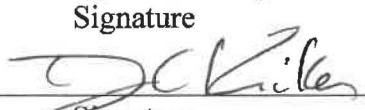
Author:	Dwayne Kicker		9/23/2020
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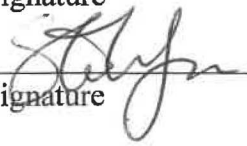
Management Review:	Steve Wagner		9/23/2020
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Executive Summary

The Department of Energy (DOE) Carlsbad Field Office (CBFO) has initiated a National Environmental Policy Act (NEPA) action for a proposal to excavate and use additional transuranic (TRU) waste disposal panels at the Waste Isolation Pilot Plant (WIPP) facility. This report documents an analysis undertaken as part of an effort to evaluate the potential environmental consequences of the proposed action. Although not explicitly required for a NEPA analysis, evaluations of a dose indicator to hypothetical members of the public after final facility closure are presented in this report.

The analysis is carried out in two stages: first, Performance Assessment (PA) calculations quantify the potential releases to the accessible environment over a 10,000-year post-closure period. Second, dose was evaluated for three hypothetical exposure pathways using the conservative radionuclide concentrations assumed to be released to the accessible environment.

The PA calculations (termed the NEPA20 PA) are based on the PA calculations performed for the 2019 Compliance Recertification Application (CRA19) submitted by the DOE to the Environmental Protection Agency (EPA). The CRA19 baseline calculations included the hypothetical scenario (based on the Certification Criteria in Title 40 CFR Part 194.41) of a lack of DOE institutional control over the WIPP facility starting from 100 years post-closure and continuing throughout the 10,000-year regulatory period; under this hypothetical scenario, inadvertent human intrusion is assumed to potentially occur over 9,900 years. Furthermore, the inventory data used in the NEPA20 analysis is based on an assumed WIPP facility closure date of 2050. Later more realistic closure dates result in smaller radionuclide activity inventory. As a result, the CRA19 calculations are conservative in nature, meaning that the calculated releases are greater than could be expected if DOE retains active institutional controls for much longer than 100 years during the 10,000 year regulatory period.

The CRA19 calculations also incorporate various sources of uncertainty. In cases where handling the uncertainty required making choices among potential assumptions, modeling assumptions were chosen such that releases exceed expectations (DOE 2019, Appendix MASS). As a result, the CRA19 calculations are conservative in nature, meaning that the calculated releases are on average greater than could be expected if there were no uncertainty in them. The NEPA20 analysis has the CRA19 conservative assumptions as its basis; however, additional modeling assumptions were made for the NEPA20 analysis and in each case where new assumptions were made, they were also chosen to be conservative. As a result, the NEPA20 calculations are also conservative in nature, meaning that the calculated releases to the accessible environment and doses to hypothetical members of the public are higher than could be expected.

The NEPA20 analysis differs from the CRA19 analysis by considering: 1) a WIPP repository consisting of 19 waste panels (18 of which contain waste); and 2) a TRU waste inventory that includes a waste stream with ~42.2 MT of surplus Pu TRU waste from the National Nuclear Security Administration (NNSA) Surplus Plutonium Disposition (SPD) project at the Savannah River Site (SRS).

WIPP PA modeling limitations make explicit modeling of the additional 9 panels computationally prohibitive, but the explicit modeling of each panel in the WIPP design has not been a part of past

WIPP PA compliance calculations. Instead, three representative waste regions have been used in the Salado flow (i.e., BRAGFLO) model when a 10-panel design has been modeled. Instead of increasing the volume of the repository in the Salado flow grid, the additional 9 panels are accounted for by assuming that they behave like a panel in the 10-panel grid, and radiological and nonradiological inventory parameters have been scaled appropriately to represent the homogenous spreading of the entire inventory across all 19 waste panels. Because releases in the 10-panel representation are themselves conservative (Zeitler et al. 2017), application of these higher representative releases to the additional 9 panels will result in higher releases than if those additional 9 panels were modeled explicitly.

The dose calculations are based on the results of conservative PA calculations (and are thus higher than could be expected) and provide mean and median doses for each of three hypothetical exposure pathways: 1) exposure of hypothetical drill rig workers to drilling debris around a mud pit for 21 days at the surface; 2) exposure of a hypothetical geologist examining drill cuttings for 1 hour at the surface; and (3) exposure of a hypothetical rancher using water from a well at the land withdrawal boundary (LWB). The drill rig workers, geologist, and rancher are not real people, but are assumed to be members of the public in hypothetical future scenarios.

The hypothetical drilling debris pathway includes exposure to solid waste brought directly to the surface during an inadvertent intrusion. The hypothetical geologist pathway includes solid and brine-dissolved waste brought to the surface. The hypothetical rancher pathway includes brine-dissolved waste transported to the LWB and subsequently pumped to the surface. For the dose calculations, a single intrusion is considered; the intrusion time and location and repository conditions are conservatively selected when the radionuclide releases are greatest. A summary of dose calculation results is provided in the table below.

This assessment is not in support of a planned change request (PCR) or planned change notice (PCN) to be submitted by the DOE to the EPA and was not performed as a compliance calculation. Instead, the planned use of this assessment is as input into a NEPA analysis. This assessment was performed in accordance with the SNL Quality Assurance Program Plan (QAPP) (SNL 2020), not SNL WIPP QA procedure NP 9-1 (Nielsen 2019).

Table ES-1: Summary of Dose Calculation Results for the NEPA20 Analysis

Release Pathway	PA Results		Mean Dose			
	Intrusion Time (yr)	Table	Table	Dose Source	Value (Sv/y)	Latent Cancer Fatality (y^{-1})
Geologist	100	Table 3-6	Table 13-5	External (only source)	3.8E-3	1.9E-4
Drilling Debris Disposal	750	Table 3-6 Table 8-1	Table 13-11	External Ingestion	2.8E-3 7.1E-5	1.3E-4 9.2E-7
Rancher	100	Table 11-2	Table 13-18	Ingestion (only Source)	2.8E-8	9.2E-10

1 Introduction

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 defense-related transuranic (TRU) waste. Containment of TRU waste at the WIPP facility is derived from standards set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191. The DOE assesses compliance with the containment standards 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 of radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure.

The DOE Carlsbad Field Office (CBFO) has initiated a National Environmental Policy Act (NEPA) action for a proposal to excavate and use additional TRU waste disposal panels at the WIPP facility. CBFO has requested Sandia National Laboratories to provide technical assistance in generating NEPA analyses. The final EIS for WIPP was completed in 1980 (DOE 1980). A supplemental EIS was completed in 1990 (SEIS-1990 (DOE 1990)) and in 1997 prior to opening WIPP a supplemental SEIS was completed (SEIS-II 1997 (DOE 1997)).

This summary report details the results of a long-term performance analysis (NEPA20) using PA calculations and a dose analysis that uses results from the PA results as input data. To meet the requirements of the SNL Quality Assurance Program Plan (QAPP) (SNL 2020), a planning document was developed that outlines the planned approach to the NEPA20 analysis (Zeitler et al. 2020). The approach taken for the NEPA20 analysis is detailed in Section 2.

The NEPA20 calculations include the hypothetical scenario (based on the Certification Criteria in Title 40 CFR Part 194.41) of a lack of DOE institutional control over the WIPP facility starting from 100 years post-closure and continuing throughout the 10,000-year regulatory period; under this hypothetical scenario, inadvertent human intrusion is assumed to potentially occur over 9,900 years. As a result, the NEPA20 calculations are conservative in nature, meaning that the calculated releases are greater than could be expected if DOE retains active institutional controls for much longer than 100 years during the 10,000 year regulatory period.

This assessment is not in support of a planned change request (PCR) or planned change notice (PCN) to be submitted by DOE to the EPA and was not performed as a compliance calculation. Instead, the planned use of this assessment is as input into a NEPA analysis. This assessment was performed in accordance with the SNL QAPP (SNL 2020), not SNL WIPP QA procedure NP 9-1 (Nielsen 2019).

In order to support the schedule for the NEPA analysis for additional panels at the WIPP, this analysis assumes the inclusion of the surplus plutonium TRU waste in the WIPP inventory so that potential impacts can be conservatively evaluated.

A flow diagram showing the relationship of PA calculations and dose calculations is provided in Figure 1-1. The structure of this summary report is outlined in Table 1-1.

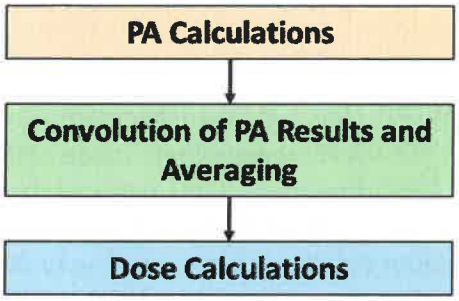

Figure 1-1: Overall Flow Diagram of NEPA20 Calculations

Table 1-1: Structure of NEPA20 Summary Report

Section	Contents
1	Introduction to the NEPA20 analysis
2	Approach taken in the NEPA20 analysis
3-7, 9, 10, 12	Analysis of results from NEPA20 PA calculations
8, 11	Conversion of PA results to appropriate input for dose calculations
13	Analysis of dose calculations
14	Summary of NEPA20 results
15	References
16	Details of computational code execution
17	Qualification of the GENII code

2 Approach

The analysis approach consists of performing a PA calculation, based on a current baseline PA analysis, that uses a new preliminary repository design and an updated TRU waste inventory estimate , followed by conservative dose calculations for three hypothetical exposure pathways. The changes made to incorporate additional TRU waste disposal panels at the WIPP are based on the most up-to-date preliminary design available at the time of the creation of the planning document (Sjomeling 2019). The updated TRU waste inventory estimate encompasses both emplaced and WIPP-bound waste streams, in addition to waste stream information associated with ~42.2 MT of surplus Pu TRU waste from the National Nuclear Security Administration (NNSA) Surplus Plutonium Disposition (SPD) project at the Savannah River Site (SRS). The inventory includes additional updates to other waste stream inventories and is used to define updated inventory and radionuclide solubility parameters for use in a PA calculation.

2.1 Baseline PA Calculation

The recently completed 2019 Compliance Recertification Application (CRA19) analysis (Zeitler et al. 2019) serves as the baseline for the PA calculations performed for this NEPA20 analysis. The CRA19 analysis includes the most up-to-date representation and parameterization of the currently approved repository design. It is therefore appropriate to base the NEPA20 analysis, which considers a new repository design incorporating additional panels, on that calculation.

The CRA19 calculations incorporated various sources of uncertainty and in cases where handling the uncertainty required making choices among potential assumptions, modeling assumptions were chosen such that releases exceed expectations (DOE 2019, Appendix MASS). As a result, the CRA19 calculations were conservative in nature, meaning that the calculated releases are on average greater than could be expected if there were no uncertainty in them. Conservative assumptions are built into calculations for all release mechanisms. The NEPA20 analysis has the CRA19 conservative assumptions as its basis; however, additional modeling assumptions (described in Section 2.2) were made for the NEPA20 analysis and in each case where new assumptions were made, they were also chosen to be conservative. As a result, the NEPA20 calculations are also conservative in nature, meaning that the calculated releases to the accessible environment and doses to hypothetical members of the public are higher than could be expected.

The inventory used in the CRA19 analysis was based on the Performance Assessment Inventory Report – 2018 (PAIR-2018), which included inventory data estimates collected through December 2017 (Van Soest 2018) and considered projected waste generation through calendar year 2033. The inventory used in the current analysis is based on the NEPA PAIR-2019 (Van Soest 2019), which includes four primary differences from the PAIR-2018: 1) inventory data was collected through December 2018; 2) two waste streams were replaced in order to represent the ~42.2 MT of surplus Pu as TRU waste from the NNSA SPD project; 3) projections for waste generation were considered through calendar year 2050; and 4) in accordance with the newly-approved container Land Withdrawal Act (LWA) TRU waste disposal volume tracking and reporting methodology,

some waste stream volumes were adjusted (DOE 2019).[1] The dose calculations performed for the current analysis will be compared with the results of the SEIS-II analysis (DOE 1997). Because this is not a compliance calculation, comparisons with EPA compliance limits will be made for illustrative purposes only. The primary results are conservative release estimates and a conservative dose analysis based on the PA results.

2.2 National Environmental Policy Act 2020 (NEPA20) Analysis

The proposed plan to excavate and use additional TRU waste disposal panels at the WIPP facility is evaluated in the NEPA20 analysis. The NEPA20 analysis consists of two sets of PA model runs: 1) the primary PA calculations consisting of three replicates each with 100 parameter samples; and 2) a supplemental calculation consisting of two vectors, one vector using mean parameter inputs and one vector using median parameter inputs. The purpose of the primary PA calculations is to support mean and median dose calculations using mean and median PA output. Results of the primary PA calculations are discussed in Sections 3 through 12. The purpose of the supplemental PA calculations is solely for comparison with dose calculations from the previous SEIS analysis by use of PA output derived from mean and median input parameters. Results of the supplemental PA calculations are not discussed in Sections 3 through 12, but the final results are used for the comparison of dose calculations discussed in Section 13.3.2.

The details of the NEPA20 analysis approach are provided in this section. A flow diagram of the NEPA20 calculations is provided in Figure 2-1. The analysis approach focuses on the changes since the CRA19 analysis and includes the topics of:

- new repository design
- updated inventory
- updated radionuclide solubilities
- updated repository layout parameters
- release calculations including the additional panels
- dose calculations.

[1] For both inventories, the projected (not yet generated) portion of the inventory was scaled up such that the total TRU waste inventory volume reflects the full legislated TRU waste volume capacity limit of the WIPP (i.e., 175,564 m^3 or 6,200,000 ft^3). The assumed incorporation of additional panels into the repository design does not change the total volume capacity limit of TRU waste which can legally be emplaced in the WIPP repository.

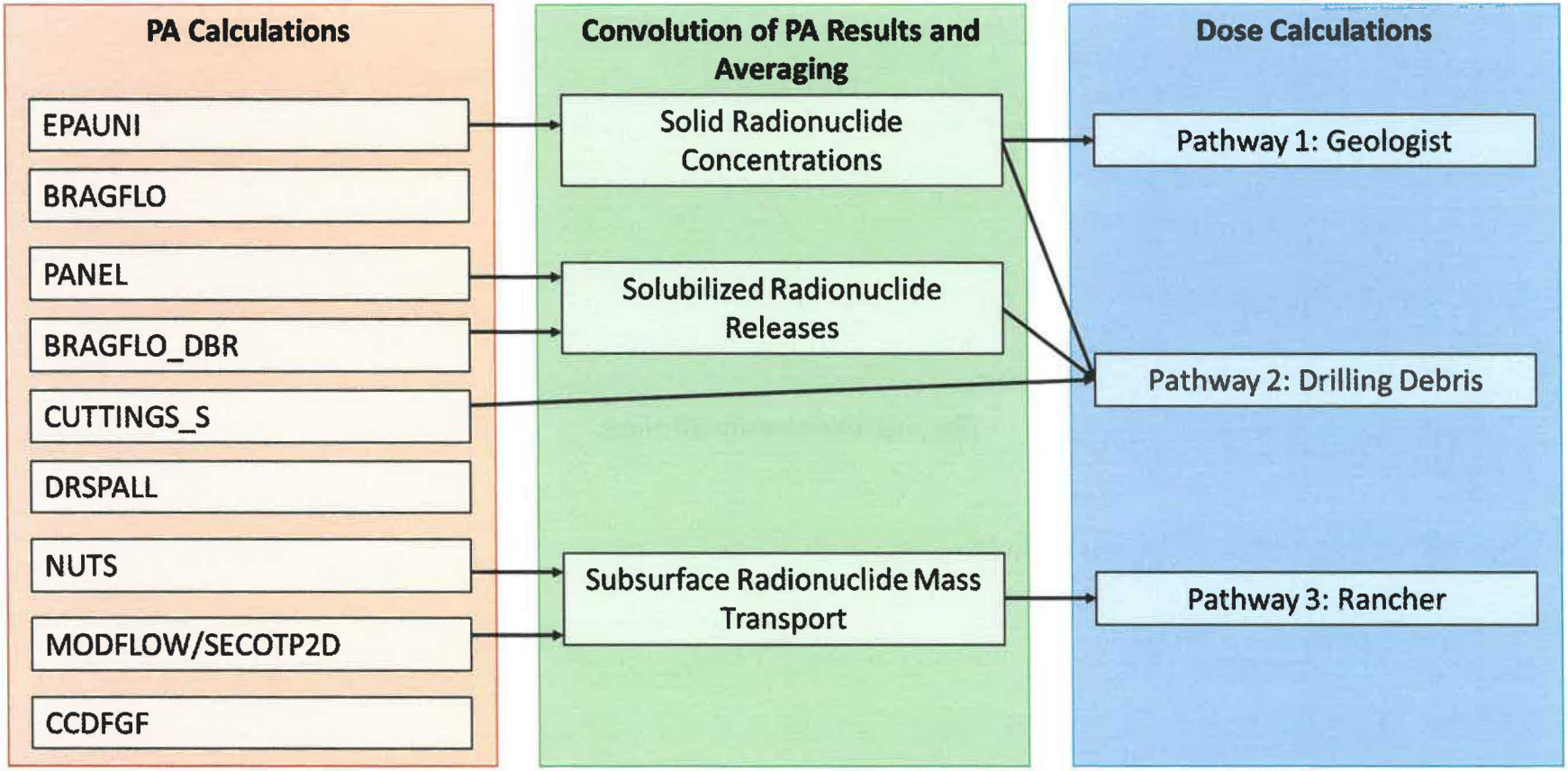

Figure 2-1: Detailed Flow Diagram for NEPA20 Calculations (interactions among PA codes omitted for clarity)

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2.2.1 New Repository Design

The preliminary design for the WIPP repository assessed here includes an expanded repository footprint and a total of 19 waste panels (the current design has 10 waste panels) (Sjomeling 2019). A final design has not yet been issued. The new preliminary design does not change the LWA total TRU waste volume capacity limit; the current design will not accommodate the full extent of the LWA inventory volume limit, so 9 additional panels have been added to the design. The new preliminary design of 19 waste panels provides sufficient floorspace to accommodate current waste inventory and packaging forecasts (Sjomeling 2019).

2.2.2 New Radionuclide and Nonradiological Inventory Information

Los Alamos National Laboratory (LANL) collects radionuclide and nonradiological inventory information from waste sites on an annual basis. An annual transuranic waste inventory report (ATWIR) is issued by LANL which includes inventory estimates of stored and projected waste through a given year, as provided by the sites. Inventory estimates are provided in terms of radionuclides on a waste stream basis, as well as inventories of non-waste components that may contribute to the long-term performance of the repository (e.g., plastics and iron). The ATWIR-2019 provided such inventory estimates (as of December 2018) through calendar year 2033 (DOE 2019). For the purposes of a PA analysis, SNL typically requests that LANL provide a PA inventory report (PAIR) that provides only the inventory information relevant to PA calculations.

For the purposes of the NEPA20 analysis, SNL requested inventory data based on the WIPP-bound inventory provided by ATWIR-2019, assuming a 2050 closure date and using a recently-approved methodology for calculating TRU waste volume. SNL also requested that inventory data be included for ~42.2 MT of surplus Pu TRU waste from the NNSA SPD project at SRS. Finally, SNL requested that the inventory data be scaled up to a full repository, as has been done in the past, assuming that a full repository would contain a volume of waste equal to the LWA volume limit.[2] As a result, the NEPA PAIR-2019 was produced by LANL, which satisfied all of the SNL requests (Van Soest 2019). Inventory data from the NEPA PAIR-2019 was used in the NEPA20 analysis.

2.2.3 Inventory Analysis for Use in NEPA20 Analysis

An SNL inventory assessment report was generated for the NEPA20 analysis based on the information provided in the NEPA PAIR-2019 (Kicker 2020). The report provides screening analyses for determining which radionuclide inventories from the NEPA PAIR-2019 are to be used in PA calculations, as well as provides parameterization of radionuclide and nonradiological inventories. Table 2-1 through Table 2-5 provide the inventory-related parameters generated by Kicker (2020) and used in the NEPA20 analysis. The radionuclide inventory parameters in Table 2-2 are used by the PANEL code (Section 7) to calculate radionuclide concentrations in brine while

[2] The inventory information is provided on a volume basis and does not consider the floorspace required for a given waste volume.

those inventory parameters are lumped together (Table 2-3) for computational efficiency in NUTS calculations for transport in the Salado formation (Section 9).

Kicker (2020) provides the inventory screening analysis, as well as values for the inventory-related input parameters used in the NEPA20 analysis. For WIPP PA compliance calculations, radionuclide inventories are converted from a curie basis to an "EPA unit" basis using the waste unit factor (WUF), which is dependent on the activity of selected radionuclides (Section 3). As a result, although the initial activity may vary from analysis to analysis, an initial PA inventory of about 10,000 EPA units always results (the number of curies per EPA unit varies from analysis to analysis). For the NEPA20 analysis, PA calculations do use EPA units for creating release CCDFs (Section 12), but releases in curies are used for the purposes of dose calculations (Section 13) and the WUF does not factor into dose calculations.

Table 2-1: Waste Unit Factor Parameter (unitless) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
BOREHOLE	WUF	Unit of Waste	16.18

NOTE: This parameter is used by PA codes EPAUNI, PANEL, NUTS, and CCDFGF.

Table 2-2: Radionuclide Inventory Parameters (Ci) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
AM241	INVCHD	Am-241 CH inventory	3.21E+06
AM241	INVRHD	Am-241 RH inventory	1.28E+04
AM243	INVCHD	Am-243 CH inventory	4.89E+01
AM243	INVRHD	Am-243 RH inventory	4.35E+02
CF252	INVCHD	Cf-252 CH inventory	2.33E-02
CF252	INVRHD	Cf-252 RH inventory	1.53E-02
CM243	INVCHD	Cm-243 CH inventory	2.47E+00
CM243	INVRHD	Cm-243 RH inventory	1.35E+01
CM244	INVCHD	Cm-244 CH inventory	7.56E+03
CM244	INVRHD	Cm-244 RH inventory	1.90E+04
CM245	INVCHD	Cm-245 CH inventory	8.48E+00
CM245	INVRHD	Cm-245 RH inventory	9.15E+00
CM248	INVCHD	Cm-248 CH inventory	1.74E+00
CM248	INVRHD	Cm-248 RH inventory	2.02E+00
CS137	INVCHD	Cs-137 CH inventory	4.91E+02
CS137	INVRHD	Cs-137 RH inventory	1.34E+05
NP237	INVCHD	Np-237 CH inventory	8.14E+01
NP237	INVRHD	Np-237 RH inventory	7.64E+00
PA231	INVCHD	Pa-231 CH inventory	4.77E+01
PA231	INVRHD	Pa-231 RH inventory	6.31E+00
PB210	INVCHD	Pb-210 CH inventory	1.71E+00
PB210	INVRHD	Pb-210 RH inventory	2.36E+01

Material	Property	Description	NEPA20 Value
PM147	INVCHD	Pm-147 CH inventory	7.07E-03
PM147	INVRHD	Pm-147 RH inventory	1.52E-01
PU238	INVCHD	Pu-238 CH inventory	1.96E+06
PU238	INVRHD	Pu-238 RH inventory	2.87E+04
PU239	INVCHD	Pu-239 CH inventory	8.77E+06
PU239	INVRHD	Pu-239 RH inventory	4.35E+03
PU240	INVCHD	Pu-240 CH inventory	2.19E+06
PU240	INVRHD	Pu-240 RH inventory	3.49E+03
PU241	INVCHD	Pu-241 CH inventory	3.04E+06
PU241	INVRHD	Pu-241 RH inventory	1.92E+04
PU242	INVCHD	Pu-242 CH inventory	4.96E+02
PU242	INVRHD	Pu-242 RH inventory	1.57E+01
PU244	INVCHD	Pu-244 CH inventory	7.49E-03
PU244	INVRHD	Pu-244 RH inventory	8.80E-02
RA226	INVCHD	Ra-226 CH inventory	2.41E+00
RA226	INVRHD	Ra-226 RH inventory	2.78E+01
RA228	INVCHD	Ra-228 CH inventory	1.13E-01
RA228	INVRHD	Ra-228 RH inventory	1.13E-02
SM147	INVCHD	Sm-147 CH inventory	1.10E-09
SM147	INVRHD	Sm-147 RH inventory	5.49E-08
SR90	INVCHD	Sr-90 CH inventory	7.49E+02
SR90	INVRHD	Sr-90 RH inventory	1.06E+05
TH229	INVCHD	Th-229 CH inventory	5.10E+00
TH229	INVRHD	Th-229 RH inventory	1.44E-01
TH230	INVCHD	Th-230 CH inventory	5.22E-01
TH230	INVRHD	Th-230 RH inventory	7.02E+00
TH232	INVCHD	Th-232 CH inventory	1.15E-01
TH232	INVRHD	Th-232 RH inventory	7.45E-03
U233	INVCHD	U-233 CH inventory	1.19E+02
U233	INVRHD	U-233 RH inventory	2.55E+01
U234	INVCHD	U-234 CH inventory	1.09E+03
U234	INVRHD	U-234 RH inventory	1.50E+01
U235	INVCHD	U-235 CH inventory	7.86E+00
U235	INVRHD	U-235 RH inventory	1.99E+00
U236	INVCHD	U-236 CH inventory	2.10E+00
U236	INVRHD	U-236 RH inventory	2.33E-01
U238	INVCHD	U-238 CH inventory	4.42E+01
U238	INVRHD	U-238 RH inventory	3.35E+00

NOTE: These inventory parameters are used by the PA codes BRAGFLO and PANEL.

Table 2-3: Lumped Radionuclide Inventory Parameters (Ci) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
AM241L	INVCHD	Am-241 Lumped CH inventory	3.31E+06
AM241L	INVRHD	Am-241 RH inventory	1.34E+04
TH230L	INVCHD	Th-230 Lumped CH inventory	5.62E+00
TH230L	INVRHD	Th-230 Lumped RH inventory	7.17E+00
PU238L	INVCHD	Pu-238 Lumped CH inventory	1.96E+06
PU238L	INVRHD	Pu-238 Lumped RH inventory	2.87E+04
U234L	INVCHD	U-234 Lumped CH inventory	1.21E+03
U234L	INVRHD	U-234 Lumped RH inventory	4.06E+01
PU239L	INVCHD	Pu-239 Lumped CH inventory	1.10E+07
PU239L	INVRHD	Pu-239 Lumped RH inventory	8.08E+03

NOTE: These lumped inventory parameters are used by PA code PANEL.

Table 2-4: Waste Material Parameters (kg) for the NEPA20 Analysis

Material	Property[a]	Description	NEPA20 Value
WAS_AREA	IRONCHW	Mass of iron-based material in CH waste	2.12E+07
WAS_AREA	IRONRHW	Mass of iron-based material in RH waste	9.20E+05
WAS_AREA	IRNCCHW	Mass of iron containers, CH waste	7.27E+07
WAS_AREA	IRNCRHW	Mass of iron containers, RH waste	1.67E+07
WAS_AREA	CELLCHW	Mass of cellulosics in CH waste	4.44E+06
WAS_AREA	CELLRHW	Mass of cellulosics in RH waste	1.32E+05
WAS_AREA	CELCCHW	Mass of cellulosics in CH waste container materials	1.21E+07
WAS_AREA	CELCRHW	Mass of cellulosics in RH waste container materials	0.00E+00
WAS_AREA	CELECHW	Mass of cellulosics in CH waste emplacement materials	3.21E+05
WAS_AREA	CELERHW	Mass of cellulosics in RH waste emplacement materials	0.00E+00[b]
WAS_AREA	PLASCHW	Mass of plastics in CH waste	5.76E+06
WAS_AREA	PLASRHW	Mass of plastics in RH waste	3.36E+05
WAS_AREA	PLSCCHW	Mass of plastic liners, CH waste	7.55E+06
WAS_AREA	PLSCRHW	Mass of plastic liners, RH waste	4.80E+05
WAS_AREA	PLSECHW	Mass of plastic in CH waste emplacement materials	3.31E+06
WAS_AREA	PLSERHW	Mass of plastic in RH waste emplacement materials	0.00E+00[b]
WAS_AREA	RUBBCHW	Mass of rubber in CH waste	9.92E+05
WAS_AREA	RUBBRHW	Mass of rubber in RH waste	3.79E+04

Material	Property[a]	Description	NEPA20 Value
WAS_AREA	RUBCCHW	Mass of rubber in CH waste container materials	1.43E+05
WAS_AREA	RUBCRHW	Mass of rubber in RH waste container materials	5.77E+03
WAS_AREA	RUBECHW	Mass of rubber in CH waste emplacement materials	4.79E+03
WAS_AREA	RUBERHW	Mass of rubber in RH waste emplacement materials	0.00E+00[b]

NOTES: [a] The waste material parameters are used by PA code BRAGFLO.
[b] The emplacement materials identified by Van Soest (2019, Table 5-7) are for CH waste only. Currently, no cellulosic, plastic, or rubber emplacement materials are used for RH waste emplacement.

Table 2-5: Oxyanion Inventory Parameters (mol) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
NITRATE	QINIT	Nitrate inventory	2.93E+07
SULFATE	QINIT	Sulfate inventory	5.26E+06

NOTE: These oxyanion inventory parameters are used by PA code BRAGFLO.

2.2.4 Features, Events, and Processes (FEPs) Assessment

For a typical compliance calculation, an assessment of the features, events, and processes (FEPs) that need to be included in the PA calculations is performed. Because the NEPA20 is not a compliance calculation, no FEPs assessment is required and none was performed; instead, the baseline FEPs used in the CRA19 analysis were used (Kirkes 2019).

2.2.5 Radionuclide Solubilities

Mobilized radionuclide concentrations used in WIPP PA calculations have a direct impact on calculated releases and are based in part on parameterized radionuclide solubilities. Radionuclide solubilities in WIPP PA are calculated based on "baseline" solubilities combined with solubility uncertainties. Baseline solubility parameters are typically updated to reflect organic ligand content in the waste inventory and are calculated using the WIPP thermodynamic database (prior to the execution of PA calculations) for two types of WIPP brine and five brine volumes. Solubility uncertainty parameters are typically updated based on recently available results in published literature. In both cases, a thermodynamic database is used in the parameterization. Baseline solubilities were updated for the NEPA20 analysis, but solubility uncertainties were not updated.

2.2.5.1 Baseline Actinide Solubilities Update

Baseline actinide solubilities were updated using the updated organic ligand inventory provided by Van Soest (2019) and the DATA0.FM5 database (Domski 2020a). The overall organic ligand inventory increased slightly, while inventories of other individual components increased or decreased. Results of the solubility analysis are documented in Domski (2020b). Solubilities were calculated for three oxidation states (+III, +IV, and +V) for two brines (GWB and ERDA-6 brines corresponding to Salado and Castile brines, respectively) and five assumed brine volumes. The baseline solubility parameters used in the NEPA20 analysis are provided in Table 2-6.

Table 2-6: Baseline Solubility Parameters (mol/L) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
SOLMOD3	SOLSOH	Oxidation state III model, solubility in the minimum volume of Salado brine	1.67E-07
SOLMOD3	SOLSOH2	Oxidation state III model, solubility in 2 × the minimum volume of Salado brine	1.60E-07
SOLMOD3	SOLSOH3	Oxidation state III model, solubility in 3 × the minimum volume of Salado brine	1.57E-07
SOLMOD3	SOLSOH4	Oxidation state III model, solubility in 4 × the minimum volume of Salado brine	1.56E-07
SOLMOD3	SOLSOH5	Oxidation state III model, solubility in 5 × the minimum volume of Salado brine	1.55E-07
SOLMOD3	SOLCOH	Oxidation state III model, solubility in the minimum volume of Castile brine	1.94E-07
SOLMOD3	SOLCOH2	Oxidation state III model, solubility in 2 × the minimum volume of Castile brine	1.72E-07
SOLMOD3	SOLCOH3	Oxidation state III model, solubility in 3 × the minimum volume of Castile brine	1.64E-07
SOLMOD3	SOLCOH4	Oxidation state III model, solubility in 4 × the minimum volume of Castile brine	1.59E-07
SOLMOD3	SOLCOH5	Oxidation state III model, solubility in 5 × the minimum volume of Castile brine	1.56E-07
SOLMOD4	SOLSOH	Oxidation state IV model, solubility in the minimum volume of Salado brine	5.45E-08
SOLMOD4	SOLSOH2	Oxidation state IV model, solubility in 2 × the minimum volume of Salado brine	5.45E-08
SOLMOD4	SOLSOH3	Oxidation state IV model, solubility in 3 × the minimum volume of Salado brine	5.45E-08
SOLMOD4	SOLSOH4	Oxidation state IV model, solubility in 4 × the minimum volume of Salado brine	5.45E-08
SOLMOD4	SOLSOH5	Oxidation state IV model, solubility in 5 × the minimum volume of Salado brine	5.45E-08
SOLMOD4	SOLCOH	Oxidation state IV model, solubility in the minimum volume of Castile brine	5.44E-08
SOLMOD4	SOLCOH2	Oxidation state IV model, solubility in 2 × the minimum volume of Castile brine	5.44E-08
SOLMOD4	SOLCOH3	Oxidation state IV model, solubility in 3 × the minimum volume of Castile brine	5.44E-08
SOLMOD4	SOLCOH4	Oxidation state IV model, solubility in 4 × the minimum volume of Castile brine	5.44E-08
SOLMOD4	SOLCOH5	Oxidation state IV model, solubility in 5 × the minimum volume of Castile brine	5.44E-08

Material	Property	Description	NEPA20 Value
SOLMOD5	SOLSOH	Oxidation state V model, solubility in the minimum volume of Salado brine	3.96E-07
SOLMOD5	SOLSOH2	Oxidation state V model, solubility in 2 × the minimum volume of Salado brine	2.79E-07
SOLMOD5	SOLSOH3	Oxidation state V model, solubility in 3 × the minimum volume of Salado brine	2.40E-07
SOLMOD5	SOLSOH4	Oxidation state V model, solubility in 4 × the minimum volume of Salado brine	2.19E-07
SOLMOD5	SOLSOH5	Oxidation state V model, solubility in 5 × the minimum volume of Salado brine	2.07E-07
SOLMOD5	SOLCOH	Oxidation state V model, solubility in the minimum volume of Castile brine	1.18E-06
SOLMOD5	SOLCOH2	Oxidation state V model, solubility in 2 × the minimum volume of Castile brine	7.11E-07
SOLMOD5	SOLCOH3	Oxidation state V model, solubility in 3 × the minimum volume of Castile brine	5.41E-07
SOLMOD5	SOLCOH4	Oxidation state V model, solubility in 4 × the minimum volume of Castile brine	4.53E-07
SOLMOD5	SOLCOH5	Oxidation state V model, solubility in 5 × the minimum volume of Castile brine	3.98E-07

2.2.6 Repository Layout Parameterization

A preliminary design has been proposed for the layout of the WIPP repository which includes additional waste disposal panels (Sjomeling 2019). The new design was incorporated into an updated model parameterization (this section) and a modified methodology for calculating releases for the additional panels (Section 2.2.7).

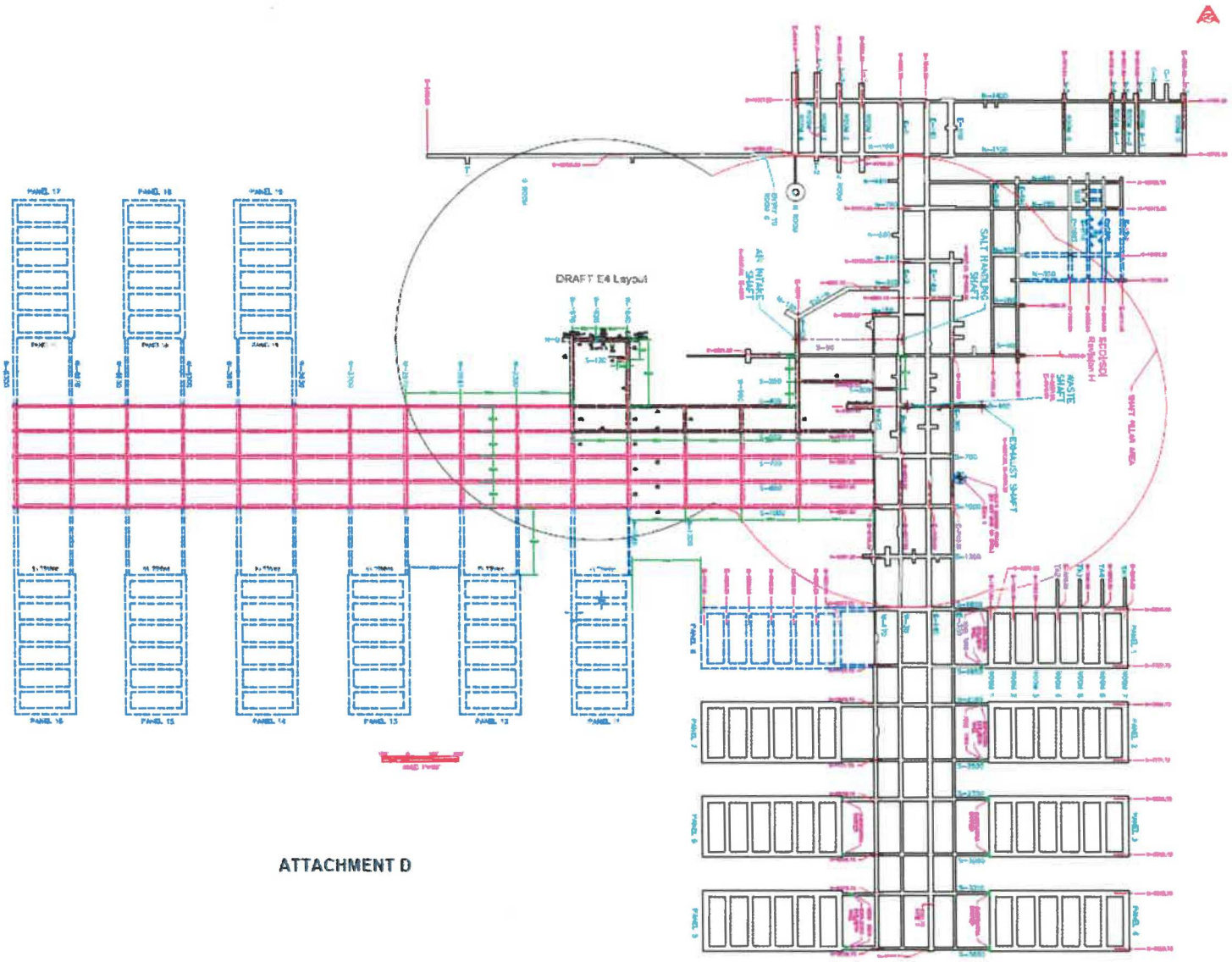

Figure 2-2: Preliminary Proposed WIPP Repository Design Including 19 Panels (Sjomeling 2019)

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2.2.6.1 Number of Waste Panels

The WIPP design has previously considered 10 waste panels. Relatively recently, Panel 9 has been abandoned for future waste emplacement (DOE 2016) with the intention that there would be no reduction in the total waste volume disposed of at the WIPP. In the PA calculations completed as part of the latest compliance application (the CRA19 analysis), the modeling assumption of 10 waste panels was used with waste assumed to be emplaced in each panel (Zeitler et al. 2019). The preliminary repository design proposed by the DOE (Sjomeling 2019) includes 19 waste panels, 18 of which are intended to contain waste (with the intention that Panel 9 will have no future waste emplacement). The PA calculations for the NEPA20 analysis include the modeling assumption of 19 waste panels, all 19 of which have waste. The difference between the modeling assumption and the repository design results in higher calculated releases as determined by the PA calculations—by assuming that all panels are filled with waste in the PA calculations, overall releases are somewhat higher than if an empty panel were to be considered explicitly. Due to the modeling limitations of the current WIPP PA infrastructure, explicit modeling of an empty panel is not possible (Zeitler et al. 2017).

WIPP PA modeling limitations also make explicit modeling of the additional 9 panels considered here computationally prohibitive, but the explicit modeling of each panel in the WIPP design has not been a part of past WIPP PA compliance calculations. Instead, only three representative waste regions have been used in the Salado flow (i.e., BRAGFLO) model when a 10-panel design has been modeled. The results of flow calculations for the three representative waste regions have been considered representative of all 10 panels. For the purposes of modeling the 19-panel repository assumed for the NEPA20 analysis, three representative waste regions are modeled.

Additionally, when multiple intrusion scenarios are considered by the direct brine release (DBR) model (Section 5), the impact of an intrusion in one panel on the pressure and saturation conditions in other panels is handled by only explicitly modeling three representative interpanel relationships (lower, middle, and upper) and later applying those results to any possible interpanel interactions. This methodology has been implemented in previous compliance calculations for computational efficiency and is carried forward for NEPA20 calculations. A description of the uses of representative waste areas and interpanel relationships is found in DOE (2019, Appendix PA).

For the purposes of modeling the 19-panel repository assumed for the NEPA20 analysis, three representative waste regions are modeled, with the volume of each waste region kept the same as in the previous 10-panel representation. Although the increased volume of the repository is not included in the Salado flow grid, radiological and nonradiological entities in those regions have been scaled appropriately to represent the homogenous spreading of the entire inventory of each across all 19 waste panels. The additional 9 panels are then accounted for by assuming that they behave like a panel in the 10-panel grid. Due to the implementation of modeling assumptions that have resulted in overestimation of releases in the 10-panel representation (Zeitler et al. 2017), application of these higher representative releases to the additional 9 panels will result in conservatively higher releases than if those additional 9 panels were modeled explicitly.

There are two representations of the repository used in WIPP PA calculations: 1) one grid for Salado flow calculations ("BRAGFLO grid") (Section 2.2.7.1) and one for direct brine release (DBR) calculations ("DBR grid") (Section 2.2.7.2). In the BRAGFLO grid representation used in CRA19, the 10 waste panels were lumped into three modeled waste areas. For the NEPA20

calculations, three modeled waste areas are also used. In the DBR grid representation used in CRA19, all 10 panels were represented individually. For the NEPA20 calculations, 10 panels are also represented, with results from the 10-panel calculations later applied to the additional 9 panels by the CCDFGF code. Release calculations done by the CCDFGF code rely on a user-specified mapping of interpanel relationships (i.e., specification of which panels neighbor each other). For CRA19 calculations, 10 panels were defined along with the interpanel relationships required to adequately map results from the DBR calculations to all panels. For NEPA20 calculations, 19 panels are explicitly defined for CCDFGF calculations such that the 9 additional panels associated with the new preliminary design have been accounted for by applying the results from a 10-panel repository model representation to a 19-panel repository (Section 2.2.7.6). Additionally, the modeling of waste in Panel 9 has been considered (Section 2.2.7.3). Because dose calculations only consider intrusion into a single panel, the explicit handling of 19 panels does not make its way into dose calculations; however, the impact of the increased volume of a 19-panel repository on dose calculations is included, as described above, via the adjustment of concentrations of radiological and nonradiological entities in the three waste areas.

2.2.6.2 Repository Volume (REFCON:VREPOS)

The parameter that represents the excavated storage volume in the repository in WIPP PA calculations is REFCON:VREPOS (hereafter VREPOS). The VREPOS parameter represents the cumulative volume of all waste panels and is used in calculating repository-wide concentrations of radionuclides and other materials. It is used in the BRAGFLO and PANEL calculations (Sections 4 and 7) and in the calculation of the FVW parameter (Section 2.2.6.4). The VREPOS value excludes the volume of Panel 9 (where no waste is emplaced, Section 2.2.6.1) and thus has been calculated such that the concentration of waste is appropriately calculated (Brunell 2020a). The value for VREPOS used in the NEPA20 analysis is provided in Table 2-7.

Table 2-7: Excavated Storage Volume Parameter (m^3) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
REFCON	VREPOS	Excavated storage volume of repository	819832.86

2.2.6.3 Repository Footprint Associated with Contact-Handled (CH) Waste (REFCON:AREA_CH)

The parameter that represents the repository footprint (i.e., area) associated with the disposal of contact-handled (CH) waste is REFCON:AREA_CH (hereafter AREA_CH). The AREA_CH parameter represents the cumulative floor area of all waste panels and is used in calculating the probability of intersecting CH waste. It is used in the CCDFGF calculations (Section 12), in which intrusion into 19 waste panels is considered. The new preliminary design proposes 19 total waste panels, so an AREA_CH associated with 19 panels has been calculated in order to maintain the appropriate intrusion probability for each panel area (Brunell 2020a). The value for AREA_CH is provided in Table 2-8.

Table 2-8: Contact-handled Waste Area Parameter (m^2) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
REFCON	AREA_CH	Area for CH Waste Disposal	216952

2.2.6.4 Volume Fraction of CH Waste (REFCON:FVW)

The parameter that represents the fraction of waste panel volume occupied by CH waste is REFCON:FVW (hereafter FVW). The FVW parameter is used to scale down the concentration of solid waste initially calculated in CCDFGF calculations in order to take into account the empty space between waste containers in the waste panels. This factor is calculated using the 19-panel VREPOS value to account for no solids being released from Panel 9. A value of FVW has been calculated using the new value of VREPOS (Brunell 2020a). The value for FVW is provided in Table 2-9.

Table 2-9: Fractional Volume of CH Waste Parameter (m^2) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
REFCON	FVW	Fraction of Waste Panel Volume Occupied by Waste	0.197

2.2.6.5 Area of Berm Above Waste Panels (REFCON:ABERM)

The parameter that represents the berm footprint above the waste areas is REFCON:ABERM (hereafter ABERM). The ABERM parameter is used in CCDFGF calculations as part of the intrusion probability calculations. The addition of a new area in the repository design for 9 additional panels has resulted in an updated calculation of the ABERM parameter (Brunell 2020a). The value for ABERM is provided in Table 2-10.

Table 2-10: Berm Area Parameter (m^2) for the NEPA20 Analysis

Material	Property	Description	NEPA20 Value
REFCON	ABERM	Berm Area	1268303

2.2.6.6 Parameters That are Unchanged

All other PA parameters not mentioned above will have their values unchanged from those used in the CRA19 analysis. Some notable cases of unchanged parameter values are discussed below.

1) **Repository Footprint Associated with Remote-Handled (RH) Waste**
   The parameter that represents the repository footprint (i.e., area) associated with the disposal of remote-handled (RH) waste is REFCON:AREA_RH (hereafter AREA_RH). The new preliminary repository design does not mention changes to the area associated with RH waste, so no change has been made to the AREA_RH parameter for the NEPA20 analysis.

2) **Volume Fraction of Remote-Handled (RH) Waste**
   The parameter that represents the fraction of repository volume occupied by RH waste is REFCON:FVRW (hereafter FVRW). The basis of FVRW is not tied to VREPOS, but rather the emplacement methodology for RH waste (Hansen 2003). The new preliminary repository design does not indicate any change to the emplacement of RH waste, so no change has been made to the FVRW parameter for the NEPA20 analysis.

3) **Probability of Intersecting Brine in Castile Formation**
The parameter that represents the probability that a drilling intrusion into the excavated region of the repository encounters a region of pressurized brine below the repository is GLOBAL:PBRINE (hereafter PBRINE). The PBRINE parameter has been developed based on subsurface information gathered for the region below the current 10-panel repository representation (U.S. EPA 2017, Zeitler 2019a). Because updated subsurface information below the additional 9 panels is not available, no change has been made to the PBRINE parameter for the NEPA20 analysis.

4) **Minimum Brine Volume Associated with a DBR**
The minimum brine volume needed for direct brine release (DBR) is used as an input to calculations of the organic ligand concentrations and actinide solubilities. The minimum brine volume for a DBR is stored as the parameter GLOBAL:DBRMINBV (hereafter DBRMINBV). The calculation of DBRMINBV was reevaluated as the previous calculation was dependent on VREPOS. It was determined that using the previous value for DBRMINBV (17,400 m^3) would be appropriately conservative over increasing the volume based on the new VREPOS value (King 2020), so no change has been made to the DBRMINBV parameter for the NEPA20 analysis.

5) **Sampled Parameters**
All sampled parameters for the NEPA20 analysis are identical to those used in the CRA19 analysis (Zeitler 2019b).

2.2.7 Release Calculation for Additional Panels

As a simplifying assumption in the NEPA20 analysis, PA calculations are done for a 10-panel portion of the repository (comprising Panels 1 through 10) and the results are extended by analogy to the additional 9 panels. This assumption is useful in order to reduce the number of changes required to current WIPP PA computational codes in order to accommodate additional panels in the NEPA20 analysis. Previous PA calculations suggest that modeling releases from the additional panels using results from the 10-panel grid is conservative (i.e., an overestimation) with respect to releases due to the increased pressures and saturations expected in the current 10-panel grid representation compared to the additional 9 panels (Section 2.2.7.6). Decreased pressures and saturations are expected in the additional panels due to the assumption of emplacement of intact panel closures in those panels (Zeitler et al. 2017, Zeitler et al. 2019). Because the WIPP PA framework currently supports the treatment of 10 waste panels as three waste areas, the extension of the results from three waste areas to 19 waste panels is also possible, without the need to explicitly model 19 waste panels in a computational grid representation. WIPP PA calculations employ two computational grids used by the BRAGFLO code.

2.2.7.1 Two-Phase Flow Computational Grid

In the BRAGFLO grid representation of the 10-panel portion of the repository (Figure 2-3), there are three waste areas defined: (1) the "waste panel" (WP) represents waste emplaced in Panel 5; (2) the "south rest-of-repository" (SROR) represents waste emplaced in Panels 3, 4, 6, and 9; and (3) the "north rest-of-repository" (NROR) represents waste emplaced in Panels 1, 2, 7, 8, and 10 (Figure 2-3). Following the Salado flow calculations using this grid, the results (pressures and saturations) are translated to a 10-panel grid representation (DBR grid). The additional 9 panels

are accounted for by assuming that they behave like a panel in the 10-panel grid (see description in Section 2.2.6.1 above). For the NEPA20 analysis, the same BRAGFLO grid representation as CRA19 was used, with pressure and saturation results from the 10-panel grid taken as representative of the 19 panel repository as described in Section 2.2.7.6.

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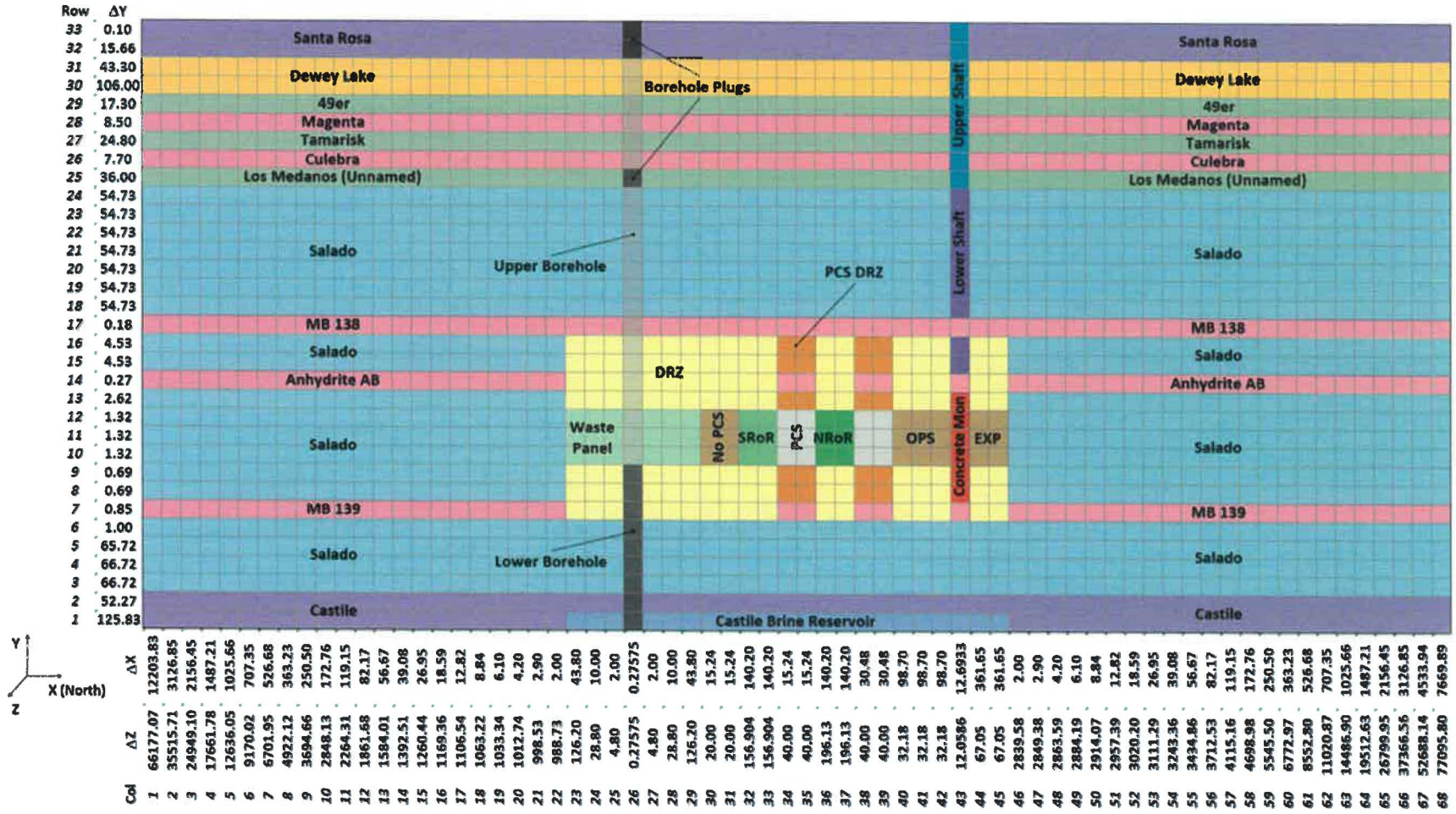

Figure 2-3: NEPA20 BRAGFLO Grid (Identical to CRA19 Grid) with Modeled Area Descriptions (Δx, Δy, and Δz Dimensions in Meters)

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2.2.7.2 Direct Brine Release (DBR) Computational Grid

In the direct brine release (DBR) grid, 10 panels are represented (Figure 2-4). The DBR grid is used in DBR volume calculations, which get initial condition information (i.e., pressures and saturations) from the BRAGFLO Salado flow results, for three possible intrusion locations (lower, middle, upper). DBR volumes are later used by the CCDFGF code when total releases are calculated for 10,000-year futures during which intrusions are possible in any of the 10 panels, in any order. DBR volume calculations using the BRAGFLO code are not calculated for every potential panel intrusion combination, but instead only a subset of potential panel intrusion combinations are assumed, with those results later applied to the other panel intrusion combinations in the CCDFGF code (WIPP PA 2010).

The NEPA20 analysis calculates DBR volumes based on three possible intrusion locations (Figure 2-4); just as those results were applied to the other panel combinations in CRA19, the DBR volume results from NEPA20 calculations will be applied to other panel combinations, including those involving the additional 9 panels (see description in Section 2.2.6.1). There is one minor change to the DBR volume calculation for the NEPA20 analysis and that is a change in the location of the upper intrusion location.

The location for an upper intrusion has been moved from Panel 10 in the CRA19 analysis to Panel 1 in the NEPA20 analysis. Within the DBR grid this appears to move the subsequent intrusion a greater distance from the first intrusion; however, it actually serves to increase the estimated releases from Upper intrusions. Within the DBR simulation time (4.5 days), there is little to no communication across panel closures, so the distance from the first intrusion (in Panel 5) to the second intrusion is not a significant factor, nor is the number of panel closures between the first and second intrusion (1 for Panel 10, 2 for Panel 1). With Panels 10 and 1 being initialized with the same pressure and saturation values (NROR values from the Salado flow model), the primary difference is the greater volume of Panel 1 over Panel 10 and the greater amount of connected DRZ to Panel 1 over Panel 10. As a result, intrusions from Panel 1 show greater releases than from Panel 10. Therefore, for a more conservative (with respect to releases) treatment of intrusion releases, Panel 1 is used as the location for Upper intrusions calculated using the BRAGFLO DBR model.

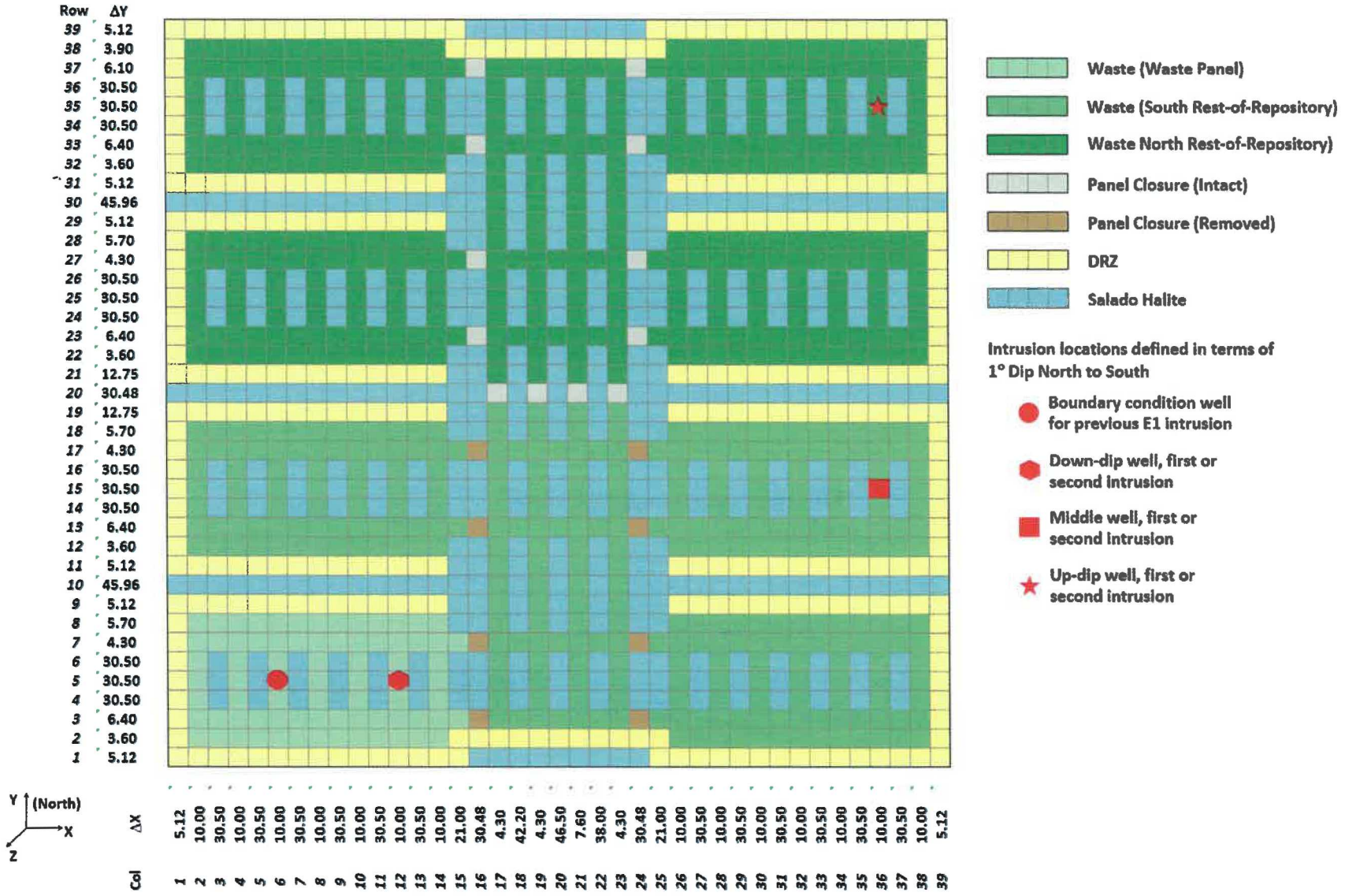

Figure 2-4: NEPA20 BRAGFLO Grid and Modeled Area Descriptions for DBR Calculations (Δx and Δy Dimensions in Meters)

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2.2.7.3 Radionuclide Concentration Calculations

Radionuclide concentrations in brine are calculated by the PANEL code using solubility limits derived from the inventory-dependent solubility parameters calculated for the NEPA20 analysis (Section 2.2.5). They are used along with calculated DBR volumes to calculate DBR releases. They are also used in dose calculations for the drilling debris pathway (directly) and rancher pathway (indirectly). The methodology used for these calculations is the same as that used for the CRA19 analysis (Sarathi 2019).

2.2.7.4 Solids Release Calculations

Cuttings, cavings, and spallings releases are calculated using the CUTTINGS_S and DRSPALL codes. They are also used in dose calculations for the rancher and drilling debris pathways. The methodology used for the PA calculations associated with cuttings, cavings, and spallings releases is the same as that used for the CRA19 analysis (Kicker 2019b).

2.2.7.5 Modeling Waste in Panel 9

The NEPA20 analysis assumes emplacement of waste in Panel 9 although Panel 9 will not contain waste. The modeling of a panel with no waste provides a challenge to the WIPP PA modeling framework. However, it was shown in previous calculations (Zeitler et al. 2017) that, from a modeling perspective, the assumption of waste emplaced in Panel 9 provided higher estimated releases compared to the assumption that Panel 9 is empty and that waste was instead emplaced in a new hypothetical panel to the west of the current repository (Zeitler et al. 2017). The emplacement of waste in Panel 9 was again assumed for the NEPA20 analysis, with additional justification provided below for the three process models impacted by this assumption.

1) **Salado Flow (BRAGFLO calculations)**
   Modeling Panel 9 as filled with waste is considered to be a conservative measure as the waste there is assumed to contribute to higher gas generation rates than if waste were not there. Neither waste-filled areas nor open areas (operations area, experimental area, abandoned panel closure area) are observed to impede flow across the repository over the time scale of Salado flow simulations, so having Panel 9 filled with waste is not modeled as introducing barrier to communication in the repository.

2) **Direct Brine Release (BRAGFLO DBR calculations)**
   Over the 4.5-day duration of a DBR simulation, DBRs are primarily driven by the pressure and saturation conditions in the panel at the time of intrusion. Very little communication between panels occurs and therefore the properties of Panel 9 will have little effect on releases from any of the intrusion locations.

3) **Total Normalized Release (CCDFGF calculations)**
   The Panel 9 area is included in the AREA_CH parameter (Section 2.2.6.3), so the probability of intrusion into the excavated region and producing DBRs is preserved. To maintain consistency, the FVW parameter (Section 2.2.6.4) is calculated using a VREPOS value representative of 19 panels, this allows solids releases from Panel 9 intrusions, which will lead to a conservative overestimation of solids releases from the system.

2.2.7.6 Extending 10-Panel Repository Results to a 19-Panel Repository

Moving from a 10-panel repository to a 19-panel repository means spreading the radiological and nonradiological inventory over a greater volume reducing the repository concentration of these items. The initial concentrations of radionuclides, steel, and CPR (cellulosics, plastics, and rubber) are inputs into BRAGFLO calculations and initial concentrations of radionuclides are inputs into PANEL calculations. The parameter values for initial, repository-wide inventories of these waste components were derived from the total inventories provided in the PAIR-2019 and documented in a separate inventory report (Kicker (2020), as well as summarized above in Section 2.2.2).

Because a 10-panel portion of the repository is modeled in BRAGFLO and PANEL calculations (Sections 2.2.7.1, 2.2.7.2, and 2.2.7.3), to achieve concentrations of radionuclides for a 19-panel repository, repository-wide inventories were scaled by a factor of the modeled repository volume (10 panels) divided by the full repository volume (19 panels). The steel and CPR inventories were converted to concentrations using the new value of the VREPOS parameter (Section 2.2.6.2), which represents the full repository volume. The radionuclide inventory, which is used in terms of mass, was scaled in a preprocessing step by a factor of the volume of repository modeled divided the actual repository volume (438406.08/819832.86=0.53475056).

While there is some communication expected between the current 10-panel repository area and the area proposed to contain an additional 9 panels (e.g., via gas pressure equilibration), the effect of this communication on calculated releases is expected to be small. With this in mind, the behavior of a model comprising only the current 10-panel repository area should be a close approximation to the behavior of the 10-panel repository area in a model that includes the additional 9 panels. Further, panels in the area proposed to contain an additional 9 panels are assumed to be more isolated from each other (i.e., greater distance between panels, more emplaced panel closures, backfilled drifts between panels), so using the current 10-panel repository representation as a surrogate for the additional panels is considered to be a conservative approximation. The additional 9 panels are considered explicitly at the stage of release calculations using the CCDFGF code (Section 2.2.6.1 and 2.2.7.7).

2.2.7.7 Waste Panel Neighbor Relationships

As discussed briefly above (Section 2.2.7.6), the panel intrusion locations considered in BRAGFLO DBR and spallings calculations do not cover all possible locations considered in CCDFGF calculations. When release calculations are done with the CCDFGF code, the results of the subset of panel intrusion locations considered in DBR and spallings calculations are mapped to all locations using a set of panel neighbor relationships derived from the physical relationship of the panels in the repository. DBR and spallings release volumes are calculated only for an initial intrusion into Panel 5 and for a subsequent intrusion into Panels 1 (part of NROR), 3 (part of SROR), and 5 (the defined waste panel (WP)).

The panel neighbor relationships define how the limited set of DBR and spallings calculations are used to estimate release volumes for other intrusions. The initial intrusion anywhere in the repository is modeled by the first intrusion at the Lower intrusion location. An intrusion into a panel that has already been intruded is modeled by the second intrusion at the Lower intrusion (Figure 2-4). An intrusion into a panel that has not been previously intruded but has a neighboring intruded panel is modeled by the Middle intrusion, with initial conditions from the South Rest of

Repository (SROR) area of the Salado flow grid. An intrusion into a panel that has not been intruded and has no intruded neighbors is modeled by the Upper intrusion with initial conditions from the North Rest of Repository (NROR) area of the Salado flow grid.

Panel neighbors are defined for the NEPA20 analysis as different panels that are not separated by a panel closure. With the operational decision to abandon the emplacement of panel closures in the south end of the repository, panel closures between the WP and the SROR are no longer modeled in WIPP PA (Zeitler et al. 2017, Zeitler et al. 2019). The WP (Panel 5) and the SROR (comprising Panels 3, 4, 6, and 9) are neighboring waste areas in the BRAGFLO grid (Figure 2-3), but are not separated by a panel closure representation. The NROR is separated from the SROR and WP by a single panel closure in the BRAGFLO grid, so panels in the NROR (comprising Panels 1, 2, 7, 8, and 10) are not neighbors to panels comprising the WP and SROR. This neighbor scheme is conservative as the single panel closure in the BRAGFLO grid is twice the width of a normal panel closure (4-drifts wide instead of 2 to represent the 4 drifts connecting Panels 9 and 10) and also because many non-neighboring panels will be actually separated by more than 1 panel closure (e.g., Panels 1 and 8 are separated by 2 panel closures). The additional panels in the new preliminary design (denoted Panels 11 through 19) would be separated from each other by at least 2 panel closures. Therefore, Panels 3, 4, 5, 6, and 9 are defined to all be neighbors to each other, while none of the other 14 panels neighbors another panel. Panel neighbor relationships used in the NEPA20 analysis are listed in Table 2-11 along with panel intrusion probabilities as used by the CCDFGF code.

Table 2-11: Panel Information for Use by CCDFGF Code[3]

Panel Number	Panel Region	Panel Intrusion Probability	Panel Neighbors
1	U	0.053662264	-
2	U	0.053662264	-
3	M	0.053662264	4, 5, 6, 9
4	M	0.053662264	3, 5, 6, 9
5	L	0.053662264	3, 4, 6, 9
6	M	0.053662264	3, 4, 5, 9
7	U	0.053662264	-
8	U	0.053662264	-
9	M	0.042154636	3, 4, 5, 6
10	U	0.045586876	-
11	U	0.053662264	-
12	U	0.053662264	-
13	U	0.053662264	-
14	U	0.053662264	-
15	U	0.053662264	-
16	U	0.053662264	-
17	U	0.053662264	-
18	U	0.053662264	-
19	U	0.053662264	-

2.2.7.8 Culebra Flow and Transport

Radionuclide transport releases to and from the Culebra are calculated using the NUTS and SECOTP2D codes. Culebra flow calculations are done with the MODFLOW code. For the NEPA20 analysis, the NUTS code was rerun, but the MODFLOW and SECOTP2D codes did not need to be rerun (Zeitler et al. 2020). These results are used in dose calculations for the rancher pathway. The methodology used for the PA calculations associated with Culebra flow and transport is the same as that used for the CRA19 analysis (Zeitler et al. 2019).

[3] Panel region indicates where initial conditions for DBR calculations are taken from in the BRAGFLO grid (L = WP, M = SROR, U = NROR). Panel intrusion probability is based on floor area; an area of 11,642.12 m^2 is used for Panels 1-8 and 11-19, while an area of 9145.52 m^2 is used for Panel 9 and area of 9890.15 m^2 is used for Panel 10 (Schreiber 1991, Brunell 2020). Due to rounding, and in order to get the sum of the probabilities to equal one, probabilities of 2E-9 and 3E-9 were added to the probabilities of Panels 9 and 10, respectively.

2.2.8 Dose Calculations

The approach to dose calculations is detailed in Section 13 and Zeitler et al. (2020). In short, the results of the NEPA20 PA calculations described above are used as inputs into the dose calculations for three exposure pathways. The PA results discussed in Sections 3 through 12 come from a full PA run of three replicates (each with 100 parameter samples) and are used as input to mean and median dose calculations using mean and median PA output—these are the principal dose calculations for the NEPA20 analysis discussed in Section 13.

A supplemental analysis is also performed for comparison with previous SEIS analysis by using only mean and median PA input parameters. The supplemental analysis consists of running the PA calculations using the same approach described in this section, but for only two vectors, one using means of sampled parameters and one using medians of sampled parameters. Results of the dose calculations using the results of the supplemental PA analysis are described in Section 13.3.2.

2.2.9 Code Execution

Run control documentation of codes executed in the NEPA20 analysis is provided in Section 16 of this report. This documentation contains:

- A description of the hardware platform and operating system used to perform the calculations.
- A listing of the codes and versions used to perform the calculations.
- A listing of the scripts used to run each calculation.
- A listing of the input and output files for each calculation.
- A listing of the library where each file is stored.
- File naming conventions.

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3 Inventory Decay: EPAUNI Calculations

This section describes the WIPP inventory over a 10,000-year regulatory compliance period. For the purposes of the NEPA20 analysis, SNL requested inventory data assuming a 2050 closure date such that the radionuclides in each waste stream have been subjected to radioactive decay and ingrowth through 2050. SNL also requested that the inventory data be scaled up to a full repository assuming that a full repository would contain a volume of waste equal to the LWA volume limit. Inventory data from the NEPA PAIR-2019 (Van Soest 2019) was used in the NEPA20 analysis. The WIPP inventory assessment is based on the PA code EPAUNI. For a more complete description of the EPAUNI calculation methodology, see Kicker (2019a).

Some WIPP PA calculations consider radiological inventory and releases in terms of EPA units rather than activity. The waste unit factor (WUF), also referred to as the "unit of waste," is defined as:

$$WUF = \frac{\sum_i W_i}{10^6 \text{Ci}} \quad (3\text{-}1)$$

where W_i is the activity in Ci at closure for α-emitting TRU repository wastes having half-lives greater than 20 years. The activity of radionuclide i at time t in EPA units, $E_i(t)$, is defined as:

$$E_i(t) = \left(\frac{1}{WUF}\right)\left(\frac{w_i(t)}{L_i}\right) \quad (3\text{-}2)$$

where $w_i(t)$ is the inventory activity for radionuclide i at time t in Ci and L_i is the EPA release limit for radionuclide i (Ci/unit of waste) as specified in 40 CFR 191 (EPA 1993). See Kicker (2020) for more information on the Ci to EPA unit conversion.

3.1 Introduction

EPAUNI calculates the time varying activity of waste, accounting for radioactive decay and ingrowth, which is used in calculating direct solid releases during a drilling intrusion (Sanchez et al. 1997). An initial waste inventory in Ci comes from the summary of an annual inventory data collection effort headed by Los Alamos National Laboratory (Van Soest 2019). The EPAUNI code then converts radionuclide activities from units of Ci to EPA units as described in Kicker (2020). For computational efficiency, only ten radionuclides are modeled for the solid release source term: ^{241}Am, ^{244}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, ^{233}U, and ^{234}U. Kicker (2020) indicates that these 10 radionuclides account for 99.98% of the EPA units of TRU waste inventory and 98.55% of the activity in Ci at the time of repository closure in the NEPA20 inventory. Calculated activities in EPA units are used in determining solid releases via the cuttings and cavings and spallings release mechanisms for a typical WIPP PA. For the purpose of dose calculations (Section 13), waste inventory in Ci is also presented.

3.2 Results

Inventory analysis results for the NEPA20 analysis (based on data from Van Soest 2019) are presented in this section.

3.2.1 Total Waste Volume

The individual waste stream volumes of TRU waste inventory shown in Table 3-1 are provided to illustrate which waste streams are the primary contributors to total waste inventory volume in the NEPA inventory. Table 3-1 shows that in the NEPA inventory, 12 wastes streams (out of a total of 602 waste streams) contribute approximately 50% of the waste volume. The top two NEPA waste streams by volume, LA-MHD01.001 and RL200-02, provide 26.25% of the total NEPA volume (Table 3-1). Note that waste streams SR-KAC-PuOx-SPD and SR-KAC-HET-SPD in Table 3-1 contain the ~42.2 MT of surplus Pu TRU waste from the SPD project that are included in the NEPA inventory,

Table 3-1: WIPP CH- and RH-TRU Waste Streams by Total Scaled Volume from NEPA Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	% of Total	Cumulative %
1	LA-MHD01.001	CH	2.55E+04	14.52%	14.52%
2	RL200-02	CH	2.06E+04	11.73%	26.25%
3	WP-BN510	CH	9.63E+03	5.48%	31.73%
4	SR-KAC-PuOx-SPD	CH	5.36E+03	3.05%	34.79%
5	WP-ID-SDA-SLUDGE	CH	4.65E+03	2.65%	37.43%
6	LA-MHD03.001	CH	4.57E+03	2.60%	40.04%
7	RLPFP-01	CH	4.34E+03	2.47%	42.51%
8	WP-RF029.01	CH	4.31E+03	2.45%	44.96%
9	SR-KAC-HET-SPD	CH	4.23E+03	2.41%	47.37%
10	WP-BN510.1	CH	3.41E+03	1.94%	49.31%
11	WP-BNINW216	CH	3.34E+03	1.90%	51.22%
12	WP-LA-MHD01.001	CH	3.10E+03	1.77%	52.98%
⋮	⋮	⋮	⋮	⋮	⋮
602	WP-LA-OS-00-04	CH	2.69E-03	0.00%	100.00%
	Total:		175,564	100.00%	

In the NEPA inventory (Van Soest 2019), the volume of anticipated and emplaced TRU waste was less than the legislated capacity for WIPP as set by the WIPP Land Withdrawal Act (U.S. Congress 1992). Because WIPP PA modeling assumes that WIPP is filled to its legislated capacity, the inventory volume of the NEPA inventory assessment was scaled up to equal the legislated capacity (total volume = 175,564 m^3 as shown in Table 3-1).

3.2.2 Inventory by EPA Units

The waste stream inventory in EPA units in Table 3-2 is provided to illustrate which waste streams are the primary contributors to the total number of EPA units over the entire population of waste streams. The table identifies the 12 waste streams that comprise 93.49% of the total inventory in EPA units at. The top two waste streams, SR-KAC-PuOx-SPD and SR-KAC-PuOx provide 67.24% and 13.57%, respectively, of the total EPA units at closure in the waste inventory. Table 3-2 shows that about 90% of the activity in the inventory comes from waste streams with greater than 100 EPA units each (top three entries).

The total number of EPA units in the NEPA waste inventory at the closure year of 2050 is 10,007 (Table 3-2). By 10,000 years post-closure, the total number of EPA units in the NEPA inventory decreases to 4,536 (Table 3-3). The top two waste streams at 10,000 years are still SR-KAC-PuOx-SPD and SR-KAC-PuOx, providing 92.26% of the total EPA units (Table 3-3); that is, these waste streams accounts for over 90% of the repository activity at the end of the regulatory time period.

Table 3-2: WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 0 (Calendar Year 2050) from NEPA Inventory

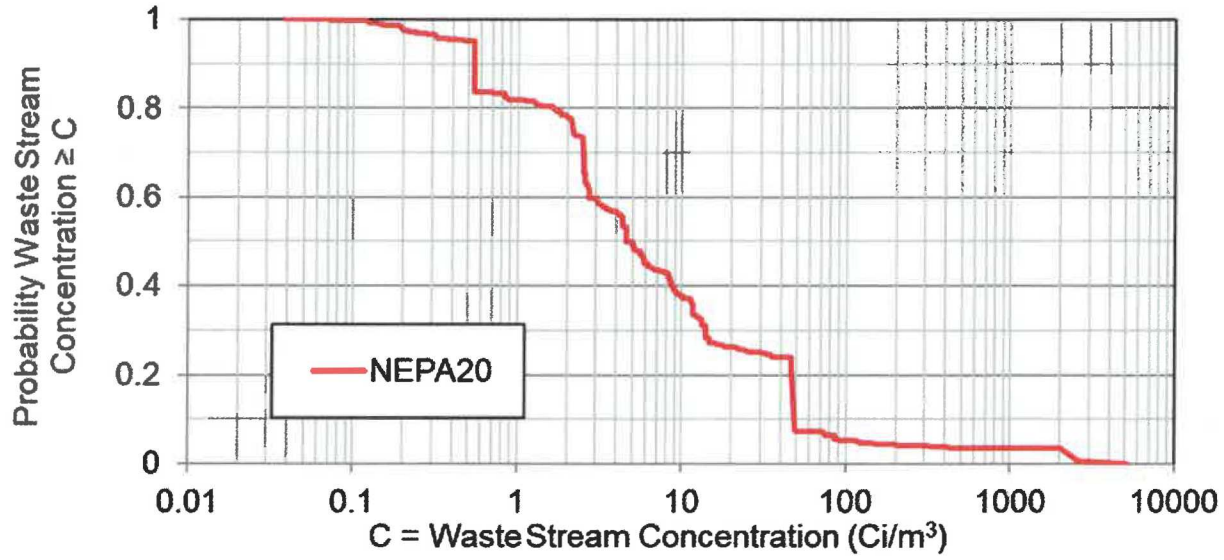
Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	SR-KAC-PuOx-SPD	CH	6.73E+03	67.24%	67.24%
2	SR-KAC-PuOx	CH	1.36E+03	13.57%	80.80%
3	LA-MHD01.001	CH	7.37E+02	7.36%	88.17%
4	WP-LA-MHD01.001	CH	8.96E+01	0.90%	89.06%
5	WP-RF009.01	CH	8.37E+01	0.84%	89.90%
6	WP-SR-W027-221	CH	7.37E+01	0.74%	90.63%
7	LA-CIN01.001	CH	6.69E+01	0.67%	91.30%
8	WP-RF118.01	CH	6.50E+01	0.65%	91.95%
9	WP-SR-MD-PAD1	CH	5.18E+01	0.52%	92.47%
10	WP-INW216.001	CH	3.56E+01	0.36%	92.83%
11	WP-SR-W027-235	CH	3.35E+01	0.33%	93.16%
12	LA-MHD03.001	CH	3.29E+01	0.33%	93.49%
⋮	⋮	⋮	⋮	⋮	⋮
602	LB-T002	CH	1.58E-07	0.00%	100.00%
	Total:		10,007	100.00%	

Table 3-3: WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 10,000 (Calendar Year 12050) from NEPA Inventory

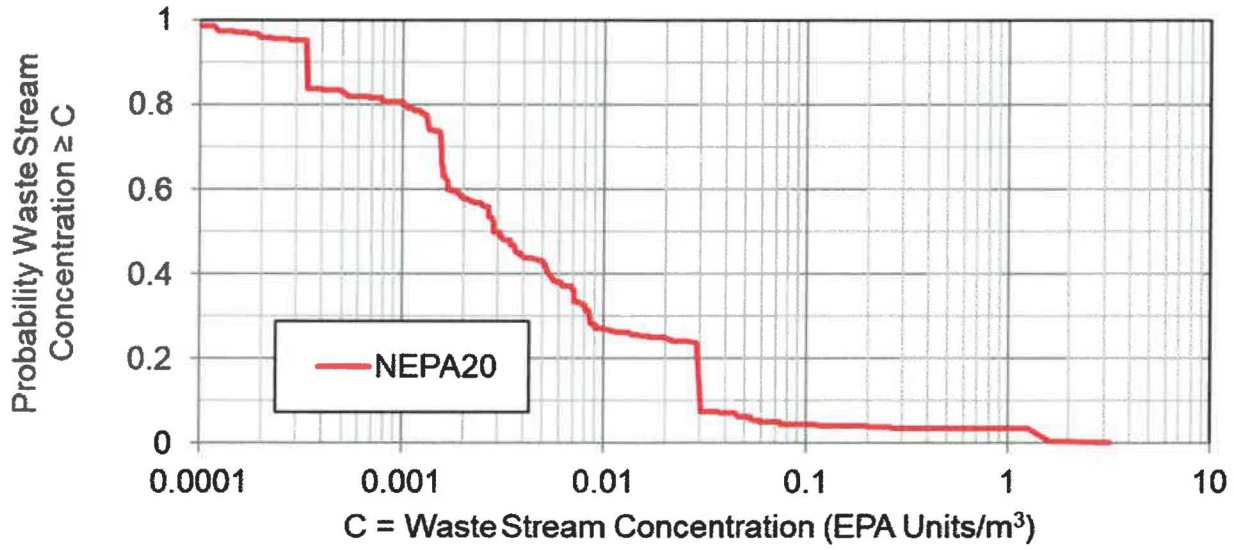
Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	SR-KAC-PuOx-SPD	CH	3.73E+03	82.32%	82.32%
2	SR-KAC-PuOx	CH	4.51E+02	9.94%	92.26%
3	LA-MHD01.001	CH	6.85E+01	1.51%	93.77%
4	WP-RF118.01	CH	3.47E+01	0.76%	94.53%
5	WP-RF009.01	CH	2.84E+01	0.63%	95.16%
6	WP-LA-MHD01.001	CH	2.37E+01	0.52%	95.68%
7	LA-MHD03.001	CH	1.80E+01	0.40%	96.08%
8	LA-CIN01.001	CH	8.66E+00	0.19%	96.27%
9	RLPURX-01	CH	7.41E+00	0.16%	96.43%
10	WP-BN510	CH	6.93E+00	0.15%	96.59%
11	WP-RF003.01	CH	6.54E+00	0.14%	96.73%
12	LL-M001	CH	6.49E+00	0.14%	96.87%
⋮	⋮	⋮	⋮	⋮	⋮
602	WP-ID-LBNL-S54	CH	1.35E-10	0.00%	100.00%
	Total:		4,536	100.00%	

3.2.3 *Waste Stream Activity Concentration*

Another important result from the running of the EPAUNI code is the activity concentration for each waste stream. Waste stream concentrations are used in cuttings and cavings release calculations (Section 12.2.1). In those calculations, waste streams are randomly selected based on waste type (contact-handled (CH) or remote-handled (RH)); within each waste type a waste stream's intersection probability is equal to the waste stream's fraction of total waste type volume. Figure 3-1 illustrates the resulting distribution of activity concentration in randomly intersected waste streams . The activity concentrations for the top 12 contributing waste streams at closure are provided in Table 3-4. In this table, the fraction of stream type volume = waste stream volume/total stream type volume. CH area = 216,952 m^2, RH area = 15,760 m^2, CH stream type area probability = 0.932, and RH stream type area probability = 0.068. The overall intersection probability = fraction of stream type volume * stream type area probability. Scatter plots of activity concentrations and waste volumes are shown in Figure 3-2.



a. Waste Stream Concentration in Ci per m^3



b. Waste Stream Concentration in EPA Units per m^3

Figure 3-1: Exceedance Probability for Waste Stream Concentration in an Intersected Waste Stream, Ci per m^3 (top) and EPA Units per m^3 (bottom) at Closure (Calendar Year 2050)

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Table 3-4: WIPP CH- and RH-TRU Waste Streams Ordered by Activity Concentration at Closure (Calendar Year 2050)

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	Activity Concentration (Ci per m^3)	EPA Units per m^3	Fraction of Stream Type Volume	Overall Intersection Probability	Cumulative Probability
1	OR-OXIDE-CH-HE	CH	6.48E-01	5.19E+03	3.20E+00	3.84E-06	3.58E-06	3.58E-06
2	SR-KAC-PuOx	CH	8.38E+02	2.62E+03	1.62E+00	4.97E-03	4.64E-03	4.64E-03
3	SR-KAC-PuOx-SP	CH	5.36E+03	2.03E+03	1.26E+00	3.18E-02	2.96E-02	3.43E-02
4	LA-LA238HOR	CH	3.56E-01	1.36E+03	8.43E-01	2.11E-06	1.97E-06	3.43E-02
5	WP-LA-OS-00-01	CH	2.08E+01	1.25E+03	7.75E-01	1.23E-04	1.15E-04	3.44E-02
6	IN-MO-530	CH	3.80E-01	9.29E+02	5.74E-01	2.25E-06	2.10E-06	3.44E-02
7	WP-LA-OS-00-04	CH	2.69E-03	9.06E+02	5.60E-01	1.60E-08	1.49E-08	3.44E-02
8	IN-MO-535	CH	1.14E+00	8.17E+02	5.05E-01	6.76E-06	6.31E-06	3.44E-02
9	LA-OS-00-01.00	CH	4.43E+01	6.26E+02	3.87E-01	2.63E-04	2.45E-04	3.47E-02
10	SR-RH-MNDPAD1.	RH	3.15E+00	5.57E+02	3.44E-01	4.45E-04	3.01E-05	3.47E-02
11	WP-RF005.02	CH	1.84E+01	5.38E+02	3.33E-01	1.09E-04	1.02E-04	3.48E-02
12	WP-SR-RL-BCLDP	RH	2.10E-01	5.13E+02	3.17E-01	2.97E-05	2.01E-06	3.48E-02
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
602	LB-T002	CH	8.35E-01	3.07E-04	1.90E-07	4.95E-06	4.62E-06	1.00E+00
	Total:		175,564	9.22E+01	5.70E-02	-	1.00E+02	-

NOTES: 1. Total CH stream type volume = 168,485 m^3; total RH stream type volume = 7,079 m^3.
2. CH area = 216,952 m^2; RH area = 15,760 m^2; CH stream type area probability = 0.932; RH stream type area probability = 0.068; stream type probability = waste stream volume/total stream type volume; overall probability = stream type probability * stream type area probability.

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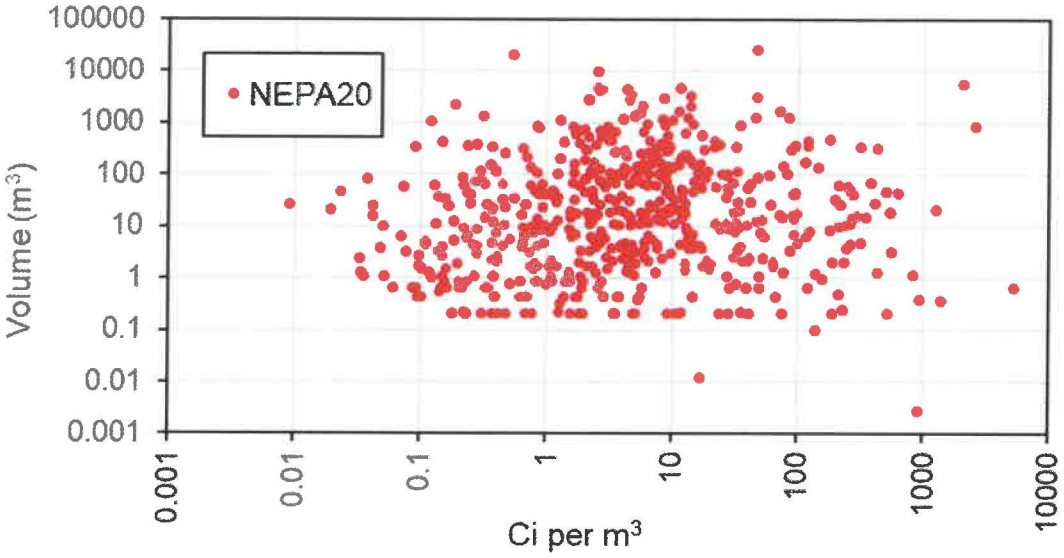
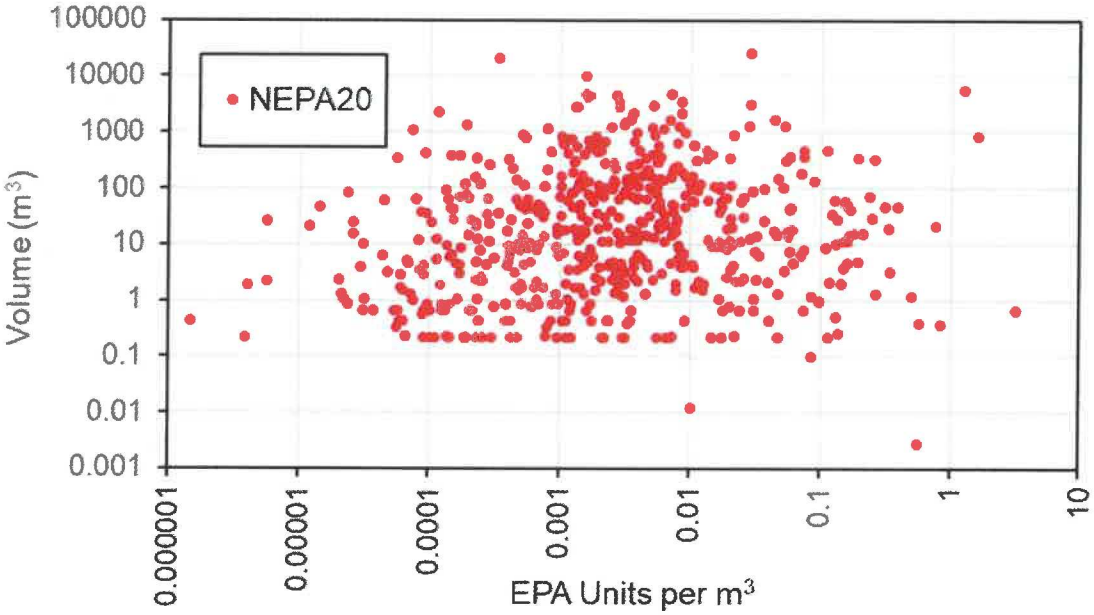


a. Activity Concentration in Ci per m^3



b. Activity Concentration in EPA Units per m^3

Figure 3-2: Scatter Plots of Activity Concentration in (a) Ci/m^3 and (b) EPA Units/m^3 with Waste Volume for WIPP CH- and RH-TRU Waste Streams at Closure (Calendar Year 2050)

At 10,000 years post-closure, the concentration of EPA units has decreased due to decay, as shown in Figure 3-3 and Table 3-5.

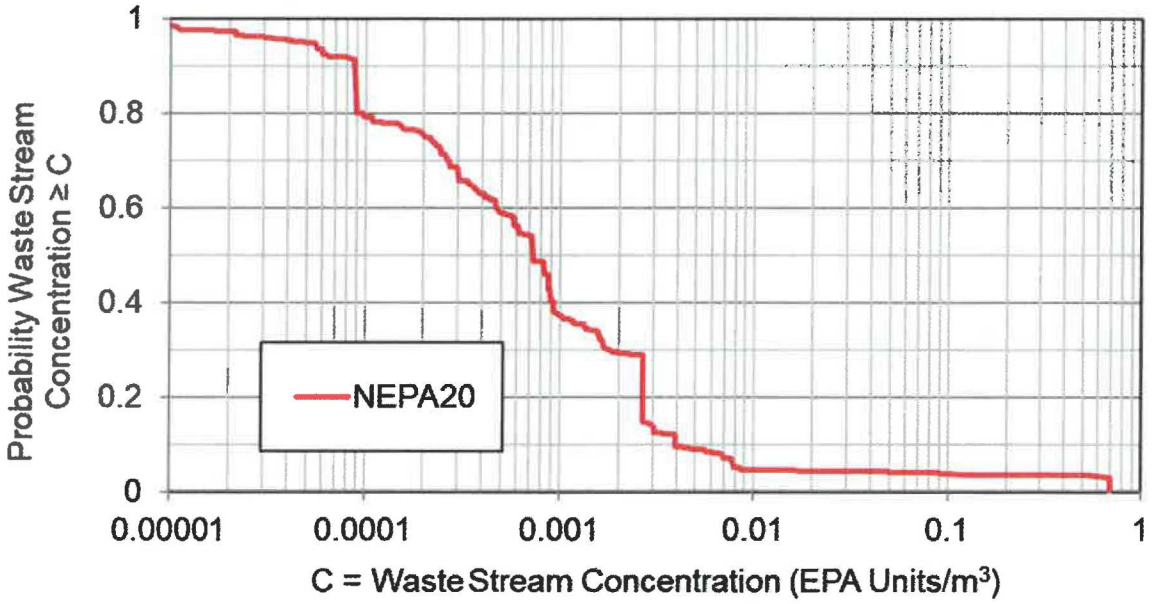


Figure 3-3: Exceedance Probability for Waste Stream Concentration in an Intersected Waste Stream at 10,000 Years After Closure (Calendar Year 12050)

Table 3-5: WIPP CH- and RH-TRU Waste Streams Ordered by Total EPA Units per Volume at 10,000 Years After Closure (Calendar Year 12050) from NEPA Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	EPA Units per m^3	Fraction of Stream Type Volume	Overall Intersection Probability	Cumulative Probability
1	SR-KAC-PuOx-SP	CH	5.36E+03	6.97E-01	3.18E-02	2.96E-02	2.96E-02
2	SR-KAC-PuOx	CH	8.38E+02	5.38E-01	4.97E-03	4.64E-03	3.43E-02
3	OR-OXIDE-CH-HE	CH	6.48E-01	3.42E-01	3.84E-06	3.58E-06	3.43E-02
4	WP-LA-OS-00-04	CH	2.69E-03	3.25E-01	1.60E-08	1.49E-08	3.43E-02
5	WP-RLRFETS.001	CH	1.50E+01	1.27E-01	8.90E-05	8.30E-05	3.44E-02
6	WP-RF118.01	CH	3.37E+02	1.03E-01	2.00E-03	1.86E-03	3.62E-02
7	WP-RLHMOX.001	CH	4.55E+01	9.72E-02	2.70E-04	2.52E-04	3.65E-02
8	WP-RF128.01	CH	4.65E+01	9.40E-02	2.76E-04	2.57E-04	3.67E-02
9	WP-RF121.01	CH	1.08E+01	9.38E-02	6.41E-05	5.97E-05	3.68E-02
10	WP-RLMSSC.001	CH	1.52E+01	9.37E-02	9.02E-05	8.41E-05	3.69E-02
11	WP-RF141.02	CH	4.13E+01	9.24E-02	2.45E-04	2.28E-04	3.71E-02
12	WP-RF009.01	CH	3.20E+02	8.86E-02	1.90E-03	1.77E-03	3.89E-02
•	•	•	•	•	•	•	•
602	ND-T002	CH	1.68E+00	1.43E-10	9.97E-06	9.29E-06	1.00E+00
	Total:		175,564	2.58E-02	-	1.00E+02	-

NOTES: Total CH stream type volume = 168,485 m^3; total RH stream type volume = 7,079 m^3. See Note 2 in Table 3-4 for probability definitions.

3.2.4 Overall Solids Activity Concentration

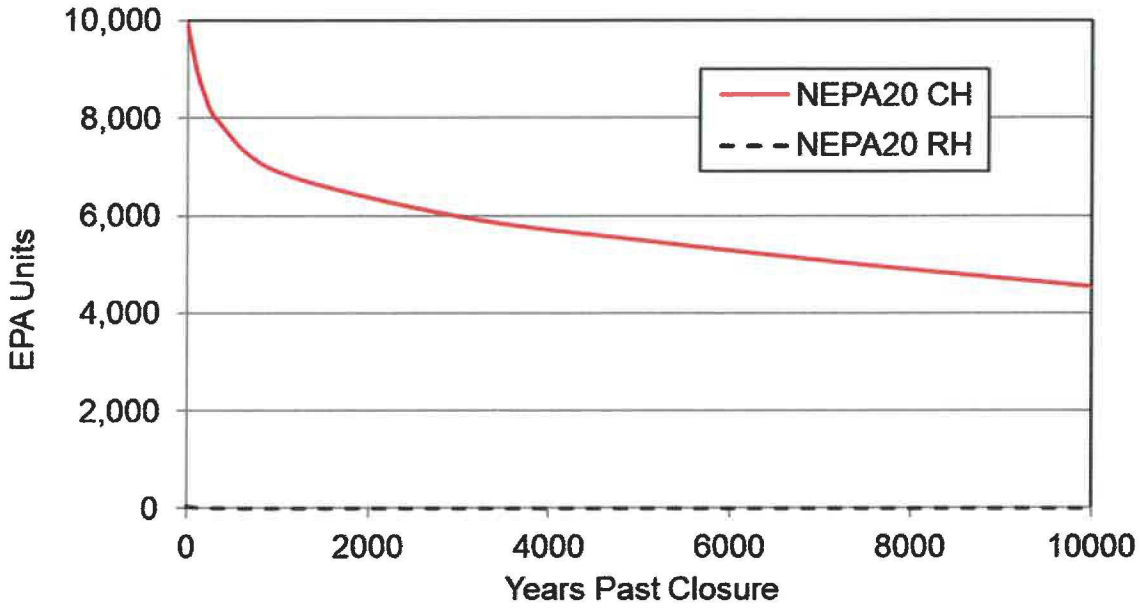
A comparison of the total activity as a function of time for the CH and RH waste inventories is shown in Figure 3-4 for both EPA units and curies. As seen in that figure, RH waste provides a minimal contribution in terms of either EPA units or curies.

A comparison of the overall activity concentration as a function of time for the NEPA waste inventory is shown in Figure 3-5. As seen in this figure, RH waste provides a minimal contribution to the overall activity concentration.

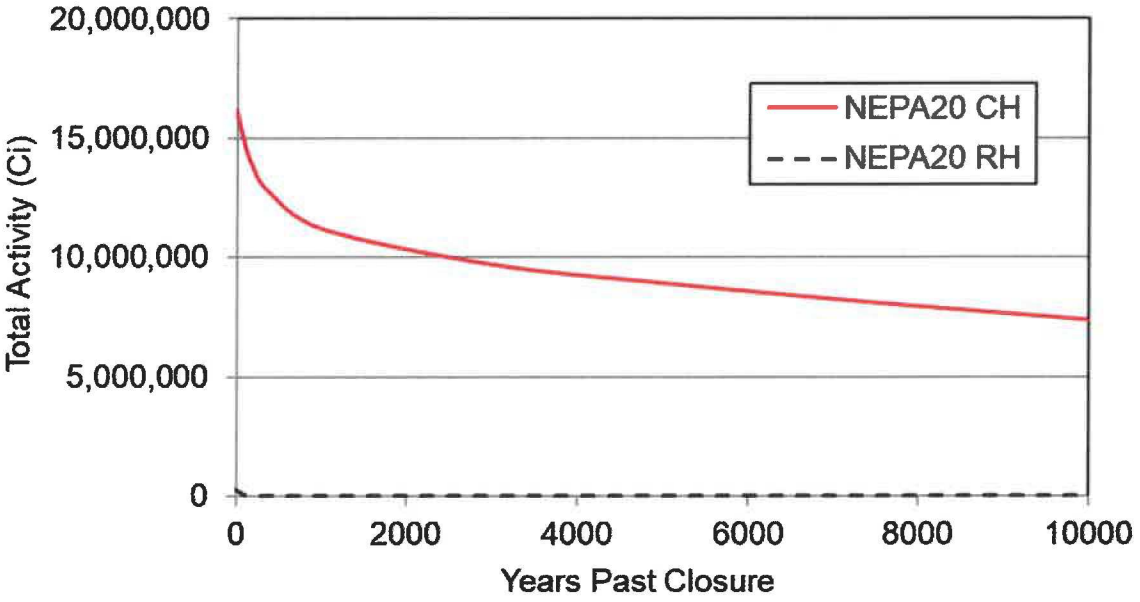
When modeling a drilling intrusion into the repository, there is an uncertainty around which waste stream will be intersected. For the dose calculation, a mean and median waste stream will be defined. The mean waste stream is defined as the mean activity concentration for each radionuclide. The median waste stream is defined by ordering all waste streams by total activity concentration and selecting the waste stream at the 50^{th} percentile. Activity concentrations at select times for the dominant radionuclides that contribute to the overall total are shown in Table 4-6 and Table 3-7. These cases are used in dose calculations (Section 13).

The total activity for dominant WIPP radionuclides is shown in Table 4-7 at closure and at 10,000 years post-closure. Figure 3-6 shows the total activity (in EPA units and Ci) as a function of time, along with the dominant radionuclides that contribute to the overall total. As seen in Figure 3-6, the initial activity of the inventory is dominated by ^{241}Am, ^{238}Pu, ^{239}Pu and ^{240}Pu.[4] The ^{241}Am and ^{238}Pu inventories decay rapidly and so the total activity of the inventory is dominated at later times (> 2,000 years) by mainly ^{239}Pu with a smaller contribution from ^{240}Pu. The radionuclides ^{244}Cm, ^{137}Cs, ^{241}Pu, ^{90}Sr, ^{233}U and ^{234}U do not appreciably contribute to the total activity at any time throughout the 10,000-year regulatory period.

[4] Only regulated radionuclides contribute to the number of EPA units of inventory available for release (Kicker 2020). For example, ^{241}Pu, while it has a high initial inventory (Van Soest 2019), does not contribute to the number of EPA units available for release due to its relatively short half-life.



a. EPA Units



b. Total Activity (Ci)

Figure 3-4: Total Activity in WIPP CH- and RH-TRU Waste from Closure to 10,000 Years after Closure

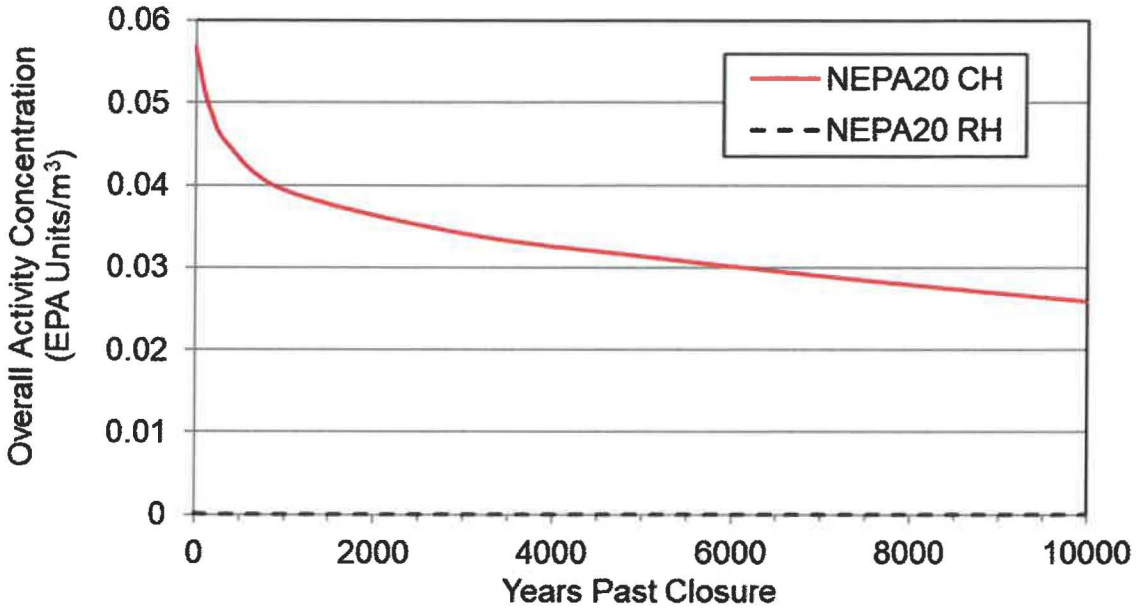


Figure 3-5: Overall Activity Concentrations in WIPP CH- and RH-TRU Waste from Closure to 10,000 Years After Closure

Table 3-6: Mean Activity Concentrations at Select Times for Dominant Radionuclides for the NEPA20 Analysis

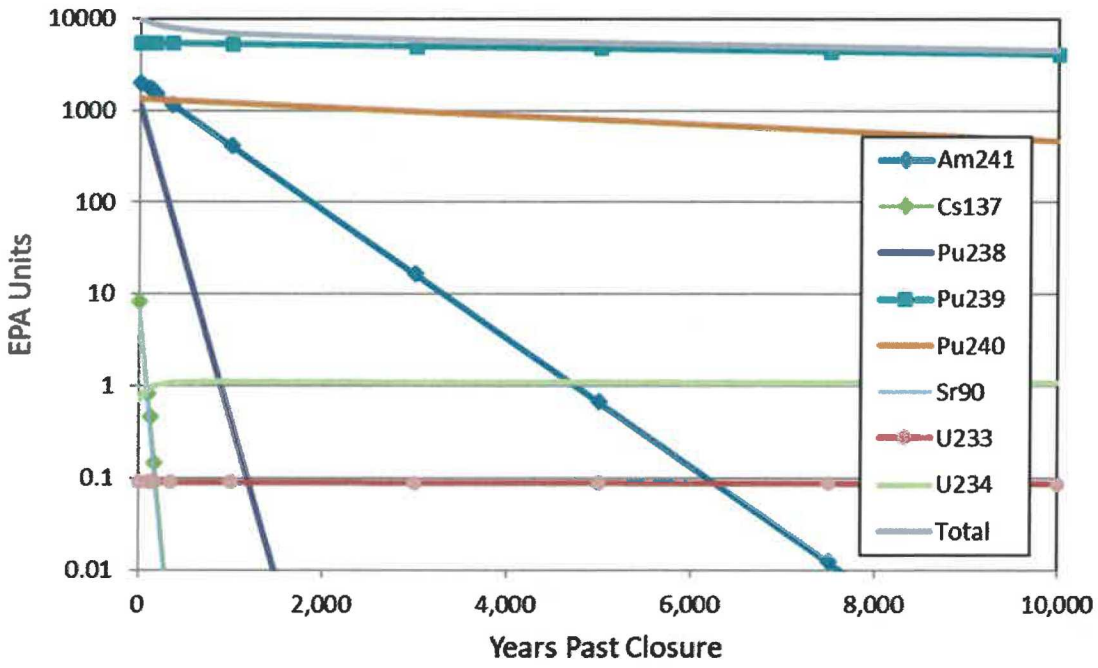
Statistic	Time (yr)	Waste	Am241 (Ci/m^3)	Pu238 (Ci/m^3)	Pu239 (Ci/m^3)	Pu240 (Ci/m^3)	U234 (Ci/m^3)
Mean	100	RH	1.617E+00	1.842E+00	6.134E-01	4.953E-01	2.920E-03
	100	CH	1.671E+01	5.273E+00	5.189E+01	1.284E+01	8.757E-03
	175	RH	1.434E+00	1.018E+00	6.120E-01	4.914E-01	3.214E-03
	175	CH	1.482E+01	2.915E+00	5.178E+01	1.273E+01	9.601E-03
	350	RH	1.083E+00	2.556E-01	6.089E-01	4.824E-01	3.487E-03
	350	CH	1.119E+01	7.318E-01	5.152E+01	1.250E+01	1.038E-02
	1000	RH	3.820E-01	1.505E-03	5.976E-01	4.503E-01	3.571E-03
	1000	CH	3.947E+00	4.309E-03	5.056E+01	1.167E+01	1.062E-02
	3000	CH	1.597E-01	5.930E-10	4.773E+01	9.441E+00	1.056E-02

Statistic	Time (yr)	Waste	Cs137 (Ci/m^3)	Sr90 (Ci/m^3)	U233 (Ci/m^3)	Total (Ci/m^3)	EPA Units ($EPAU/m^3$)
Mean	100	RH	1.875E+00	1.381E+00	3.607E-03	4.899E+00	3.028E-03
	100	CH	2.889E-04	4.113E-04	7.072E-04	8.669E+01	5.360E-02
	175	RH	3.314E-01	2.316E-01	3.606E-03	3.619E+00	2.237E-03
	175	CH	5.107E-05	6.900E-05	7.069E-04	8.228E+01	5.084E-02
	350	RH	5.812E-03	3.597E-03	3.603E-03	2.438E+00	1.507E-03
	350	CH	8.956E-07	1.071E-06	7.064E-04	7.596E+01	4.694E-02
	1000	RH	1.746E-09	6.870E-10	3.593E-03	1.439E+00	8.892E-04
	1000	CH	2.690E-13	2.046E-13	7.044E-04	6.619E+01	4.091E-02
	3000	CH	2.296E-33	4.337E-34	6.983E-04	5.734E+01	3.544E-02

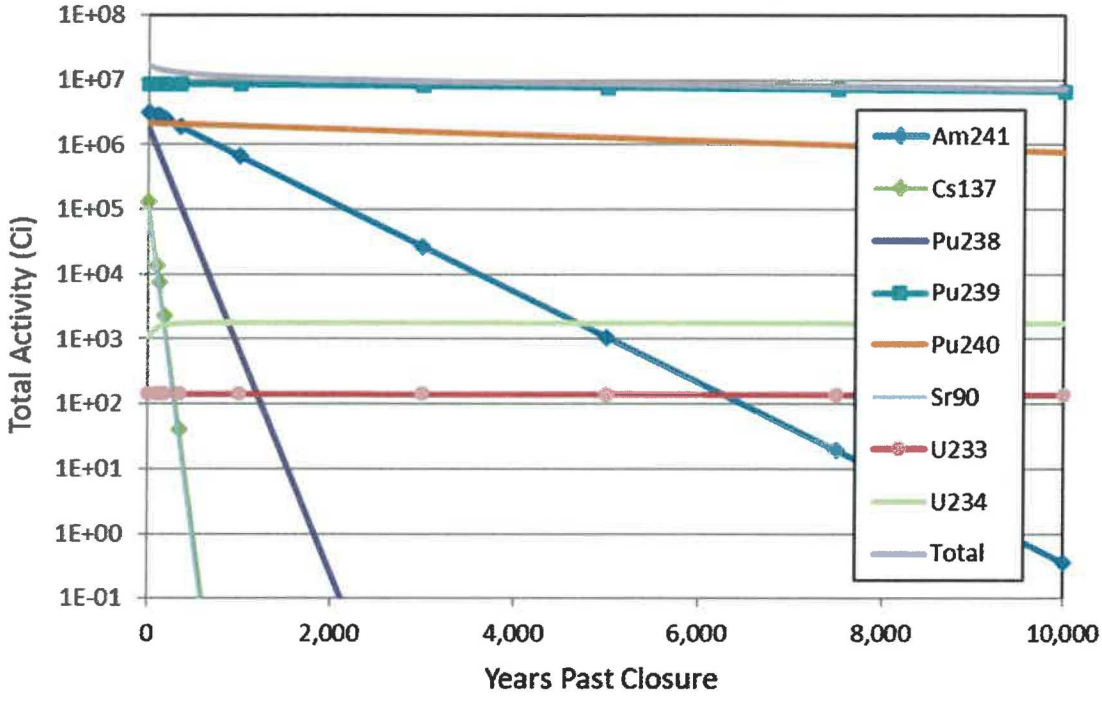
Table 3-7: Median Activity Concentrations at Select Times for Dominant Radionuclides for the NEPA20 Analysis

Statistic	Time (yr)	Waste	Am241 (Ci/m³)	Pu238 (Ci/m³)	Pu239 (Ci/m³)	Pu240 (Ci/m³)	U234 (Ci/m³)
Median	100	RH	8.148E-01	3.456E-02	5.394E-01	2.069E-01	2.469E-05
	100	CH	2.136E+00	3.043E-01	5.680E-01	4.801E-01	2.728E-04
	175	RH	2.942E-01	4.663E-02	6.218E-01	2.426E-01	2.090E-03
	175	CH	7.119E-01	1.283E-01	1.117E+00	5.076E-01	5.039E-03
	350	RH	2.299E-01	2.290E-03	2.340E-01	6.100E-01	2.144E-05
	350	CH	4.805E-01	3.524E-03	1.605E+00	3.602E-01	2.776E-05
	1000	RH	1.491E-02	2.873E-06	8.544E-01	0.000E+00	6.429E-03
	1000	CH	6.443E-02	1.369E-03	1.169E+00	2.563E-01	2.520E-03
	3000	CH	5.883E-03	1.574E-11	9.468E-01	1.792E-01	1.972E-04

Statistic	Time (yr)	Waste	Cs137 (Ci/m³)	Sr90 (Ci/m³)	U233 (Ci/m³)	Total (Ci/m³)	EPA Units (EPAU/m³)
Median	100	RH	5.366E-03	3.864E-03	1.136E-04	1.597E+00	9.869E-04
	100	CH	0.000E+00	0.000E+00	3.554E-09	3.489E+00	2.156E-03
	175	RH	1.642E-01	1.178E-01	1.612E-03	1.237E+00	7.645E-04
	175	CH	1.356E-03	1.944E-03	3.997E-01	2.870E+00	1.773E-03
	350	RH	0.000E+00	0.000E+00	1.162E-09	1.076E+00	6.650E-04
	350	CH	0.000E+00	0.000E+00	2.662E-09	2.450E+00	1.514E-03
	1000	RH	8.549E-10	8.989E-12	6.243E-11	8.757E-01	5.413E-04
	1000	CH	8.912E-17	0.000E+00	5.137E-05	1.494E+00	9.230E-04
	3000	CH	4.976E-37	5.764E-38	5.194E-03	1.137E+00	7.028E-04



a. EPA Units



b. Total Activity (Ci)

Figure 3-6: Total Activity for Dominant Isotopes in WIPP CH and RH-TRU Waste Streams in EPA Units (top) and Ci (bottom) from Closure to 10,000 Years

Table 3-8: Total Activity for Dominant Isotopes in WIPP CH- and RH-TRU Waste at Closure and After 10,000 Years

Radionuclide	Half-life (y)	Activity at Closure		Activity after 10,000 Years	
		Ci	EPA Units	Ci	EPA Units
Am241	432.7	3.22E+06	1.99E+03	3.60E-01	2.23E-04
Cm244	18.1	2.66E+04	—	0.00E+00	—
Cs137	30.07	1.34E+05	8.29E+00	0.00E+00	0.00E+00
Pu238	87.7	1.99E+06	1.23E+03	9.80E-29	6.06E-32
Pu239	24100	8.77E+06	5.42E+03	6.58E+06	4.07E+03
Pu240	6560	2.19E+06	1.35E+03	7.59E+05	4.69E+02
Pu241	14.29	3.05E+06	—	0.00E+00	—
Sr90	28.8	1.06E+05	6.57E+00	0.00E+00	0.00E+00
U233	159200	1.45E+02	8.94E-02	1.39E+02	8.56E-02
U234	246000	1.11E+03	6.85E-01	1.77E+03	1.09E+00
Total		1.95E+07	1.00E+04	7.34E+06	4.54E+03

NOTE: Half-life provided by Kicker (2020). EPA units are calculated for each radionuclide based on EPAUNI output activity (Ci), radionuclide release limits (Kicker 2020), and the waste unit factor (Kicker 2020).

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4 Salado Flow: BRAGFLO Calculations

This section describes the modeling of flow of brine and gas in the vicinity of the WIPP repository over a 10,000-year regulatory compliance period. The results of these calculations are used by other codes to calculate potential radionuclide releases to the accessible environment. For a more complete description of the Salado flow computational procedures, refer to the Salado flow analysis package for CRA-2019 (Day, 2019).

4.1 Introduction

The PA code BRAGFLO calculates subsurface brine and gas flow in the repository and the surrounding area over a 10,000-year period using a two-dimensional, "flared" vertical cross section representation of the repository and surrounding area. In this grid representation (Figure 2-3), there are three waste areas: (1) the "waste panel" (WP) represents waste emplaced in Panel 5; (2) the "south rest-of-repository" (SROR) represents waste emplaced in Panels 3, 4, 6, and 9; and (3) the "north rest-of-repository" (NROR) represents waste emplaced in Panels 1, 2, 7, 8, and 10. As described in Section 2.2.7.6 above, the results of modeling a 10-panel portion of the repository are extended to the additional 9 panels.

There are two non-waste areas modeled, the operations (OPS) area and the experimental (EXP) area. There are also three panel closure areas (PCS): the "southernmost" PCS representation is between the WP and SROR (modeled as an abandoned panel closure with PCS_NO material properties), the "middle" PCS representation is between the SROR and NROR, and the "northernmost" PCS representation is between the NROR and OPS area.

In BRAGFLO calculations, stochastic uncertainty is addressed by defining a set of six scenarios which vary in the time and type of intrusion. The total number of BRAGFLO simulations executed in the NEPA20 PA is 1,800 (300 vectors times 6 scenarios). The scenarios include one undisturbed scenario (S1-BF), four scenarios that include a single inadvertent future drilling intrusion into the repository during the 10,000-year regulatory period (S2-BF to S5-BF), and one scenario investigating the effect of two intrusions into a single waste panel (S6-BF).

Two types of intrusions, denoted as E1 and E2, are considered. An E1 intrusion assumes the borehole passes through a waste-filled panel and into a pressurized brine pocket that may exist under the repository in the Castile formation. An E2 intrusion assumes that the borehole passes through the repository but does not encounter a brine pocket. Scenarios S2-BF and S3-BF model the effect of an E1 intrusion occurring at 350 years and 1,000 years, respectively, after the repository is closed. Scenarios S4-BF and S5-BF model the effect of an E2 intrusion at 350 and 1,000 years. Scenario S6-BF models an E2 intrusion occurring at 1,000 years, followed by an E1 intrusion into the same panel at 2,000 years. Table 4-1 summarizes the six scenarios used in this analysis.

Epistemic uncertainty in, for example, material properties, is addressed by parameter sampling. Uncertain parameters are sampled in three independent replicates each of size 100; an element in one sample is termed a vector as it comprises values for each uncertain parameter. The total number of BRAGFLO simulations executed in the NEPA20 PA is 1,800 (300 vectors times 6 scenarios).

Table 4-1: BRAGFLO Modeling Scenarios

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

4.2 Results

Salado flow results obtained for NEPA20 are now presented. Results are discussed in terms of means for quantities calculated over all 300 vectors (100 vectors in each of three replicates).

Results are presented for all scenarios, generally plotted on the same graph. Results associated with an E1 intrusion, scenarios S2-BF and S3-BF, generally follow the same trends with the only difference being the timing of the drilling intrusion. Similarly, results associated with an E2 intrusion, S4-BF and S5-BF, also follow the same tends. Results from BRAGFLO scenario S1-BF and S6-BF are also discussed.[5]

4.2.1 Pressure

Plots of the mean brine pressure through time for the experimental area, operations area, north rest-of-repository, south rest-of-repository, and the waste panel are presented in Figure 4-1 through Figure 4-5. In the undisturbed case (S1-BF), pressures generally increase through time in all areas. Non-waste areas (EXP and OPS) see less pressure increase than the waste areas (NROR, SROR, and WP). This is due to the gas generation from iron corrosion; biodegradation of cellulose, plastic, and rubber (CPR); and radiolysis of brine that occurs in the waste areas.

Scenarios that include an E1 intrusion (S2-BF, S3-BF, and late time S6-BF), have increased pressures compared to the undisturbed scenario. The Castile brine flowing into the repository from the pressurized brine pocket and increased gas generation due to the higher brine saturations cause this increased pressure.

Scenarios that include a E2 intrusion (S4-BF and S5-BF) have a decreased pressure compared to the undisturbed scenario. The decrease in pressure is due to the borehole increasing communication between the repository and the overburden.

In general, the Run-of-mine Panel Closure Systems (ROMPCS) in the north end of the repository slow communication considerably compared the south end of the repository where the panel closures were abandoned (DOE 2016). For this reason, the Waste Panel and the South Rest-of-Repository have very similar results to intrusion events in the Waste Panel, where the North Rest-

[5] In the results that follow, summary statistics and plots were generated with Python, an open-source software package.

of-Repository, Operations, and Experimental areas have much more muted responses to intrusion events. Pressure statistics for NEPA20 are summarized in Table 4-2. In Table 4-2 the 3-replicate mean (integrated over time) and 3-replicate maximum (over all time) pressure values are presented.

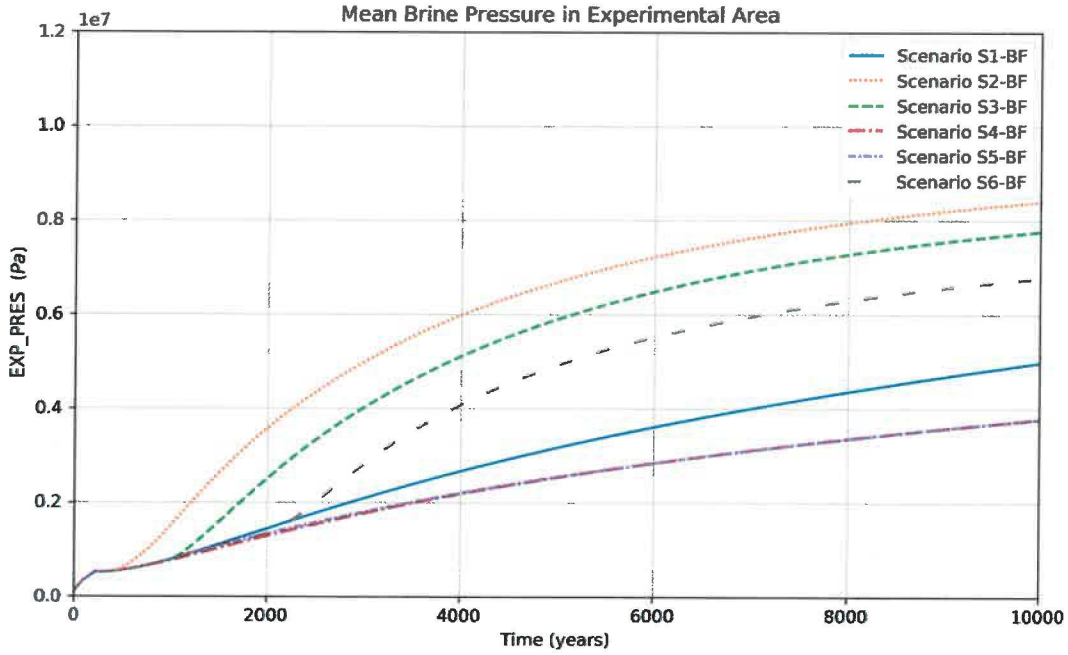

Figure 4-1: Means of Pressure in the Experimental Area

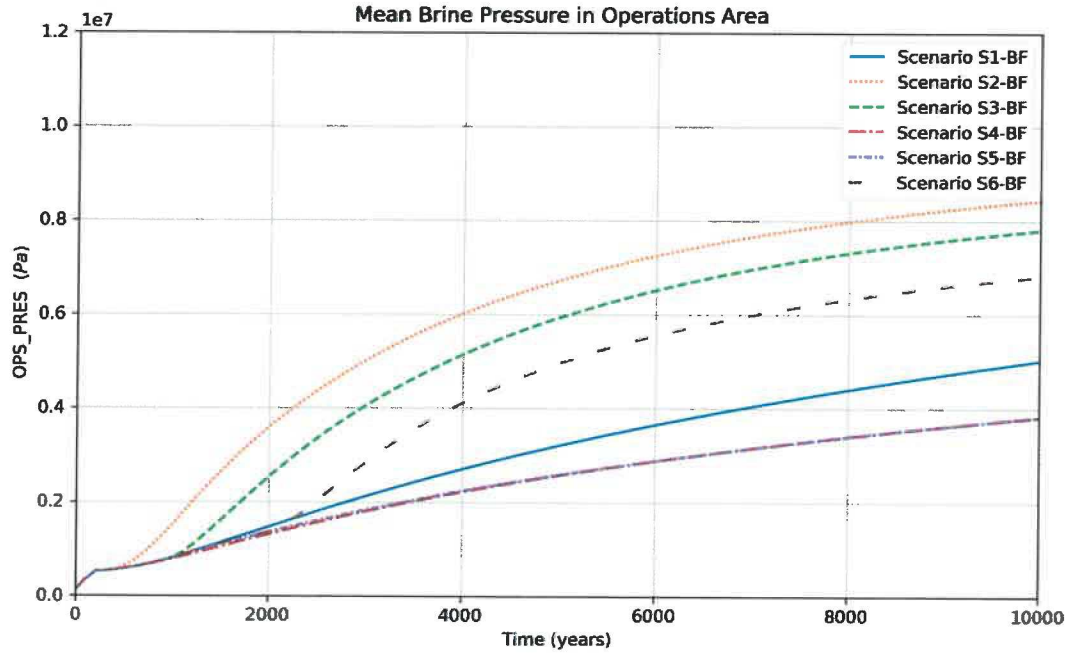

Figure 4-2: Means of Pressure in the Operations Area

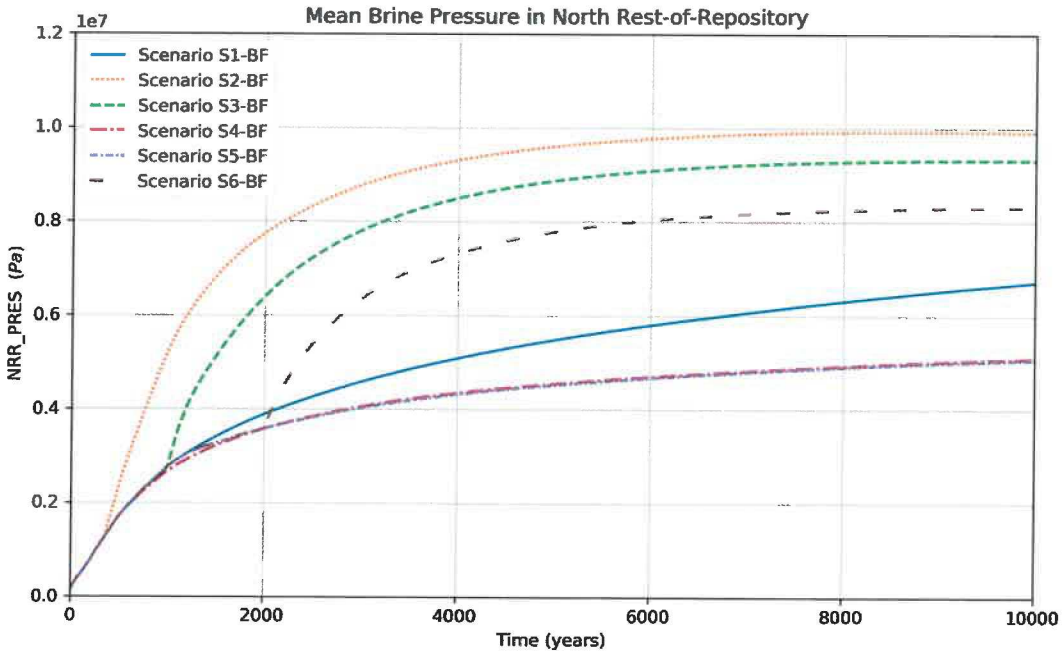

Figure 4-3: Means of Pressure in the North Rest-of-Repository

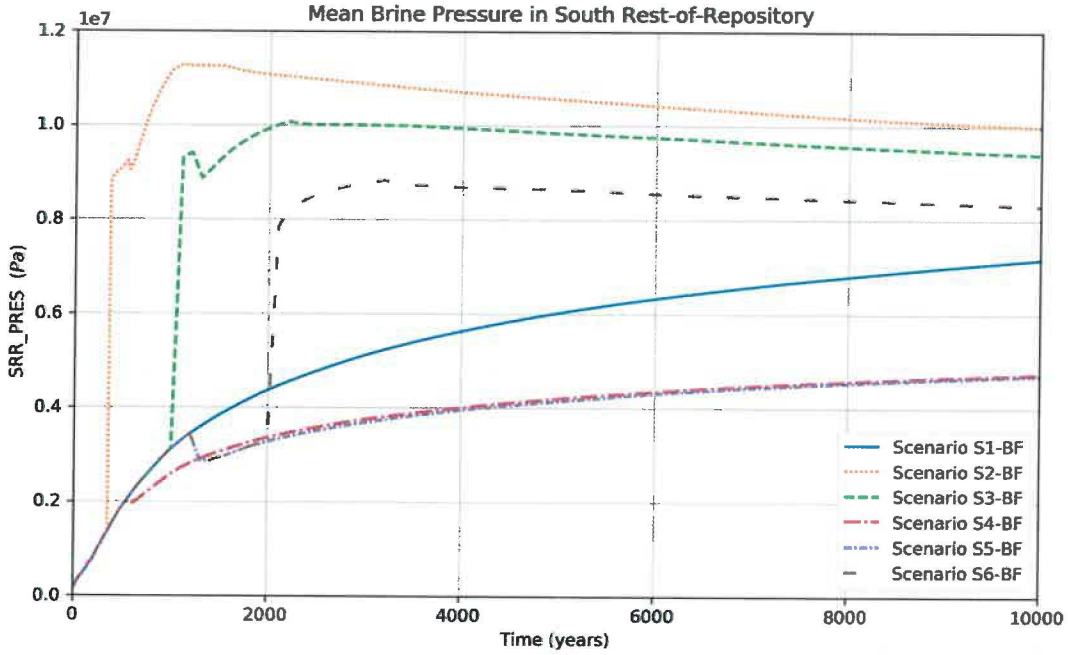

Figure 4-4: Means of Pressure in the South Rest-of-Repository

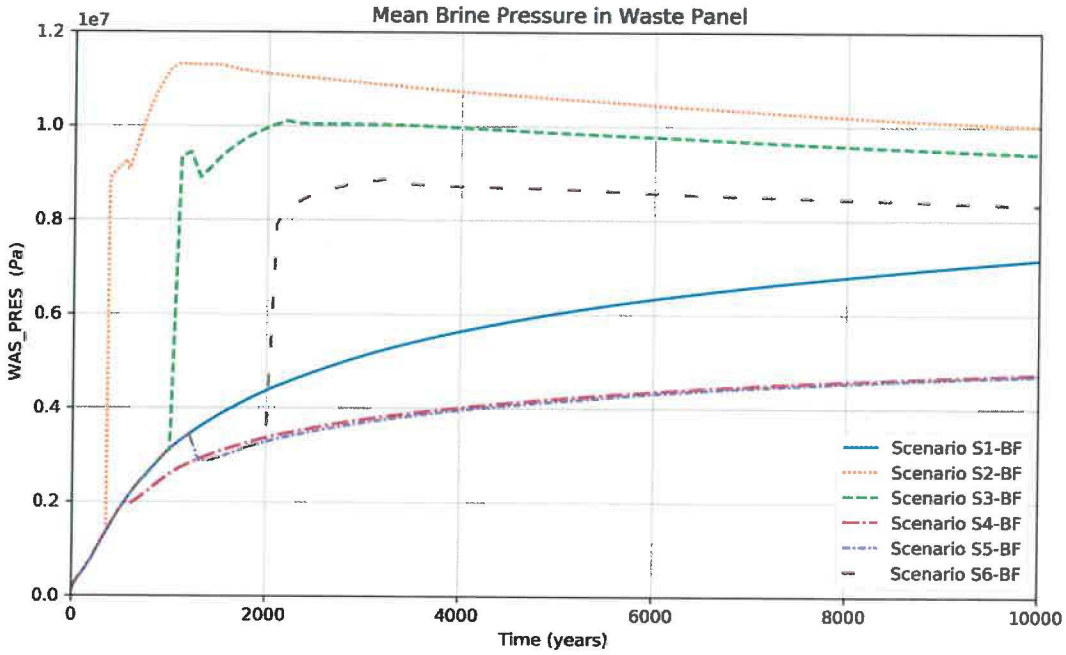

Figure 4-5: Means of Pressure in the Waste Panel

Table 4-2: Statistics for Mean Pressures for NEPA20

Quantity (units)	Description	Scenario	Time-Averaged Mean Pressure (Pa)[1]	Maximum Pressure[2]
EXP_PRES (Pa)	Brine Pressure in Experimental Area	S1-BF	2.95E+06	4.98E+06
		S2-BF	5.80E+06	8.39E+06
		S3-BF	5.07E+06	7.77E+06
		S4-BF	2.34E+06	3.76E+06
		S5-BF	2.36E+06	3.77E+06
		S6-BF	4.18E+06	6.77E+06
OPS_PRES (Pa)	Brine Pressure in Operations Area	S1-BF	2.99E+06	5.03E+06
		S2-BF	5.83E+06	8.42E+06
		S3-BF	5.10E+06	7.81E+06
		S4-BF	2.38E+06	3.81E+06
		S5-BF	2.40E+06	3.82E+06
		S6-BF	4.22E+06	6.81E+06
NRR_PRES (Pa)	Brine Pressure in North Rest-of-Repository	S1-BF	5.02E+06	6.72E+06
		S2-BF	8.52E+06	9.91E+06
		S3-BF	7.67E+06	9.32E+06
		S4-BF	4.15E+06	5.08E+06
		S5-BF	4.14E+06	5.06E+06
		S6-BF	6.54E+06	8.30E+06
SRR_PRES (Pa)	Brine Pressure in South Rest-of-Repository	S1-BF	5.49E+06	7.17E+06
		S2-BF	1.01E+07	1.13E+07
		S3-BF	8.88E+06	1.01E+07
		S4-BF	3.86E+06	4.73E+06
		S5-BF	3.86E+06	4.70E+06
		S6-BF	7.28E+06	8.83E+06
WAS_PRES (Pa)	Brine Pressure in Waste Panel	S1-BF	5.49E+06	7.17E+06
		S2-BF	1.02E+07	1.13E+07
		S3-BF	8.91E+06	1.01E+07
		S4-BF	3.87E+06	4.73E+06
		S5-BF	3.86E+06	4.71E+06
		S6-BF	7.30E+06	8.85E+06

Notes:
1 Calculated as the function average (integrated) over the time interval (0-10,000 y) for the overall means
2 Calculated as the function maximum over the time interval (0-10,000 y) for the overall means

4.2.2 Brine Saturation

Plots of brine saturation in the EXP, OPS, NROR, SROR, and WP areas are shown in Figure 4-6 through Figure 4-10. In the undisturbed case (S1-BF), brine saturation generally increases over time in non-waste areas (EXP and OPS). In waste areas (NROR, SROR, and WP), brine saturation reaches a maximum value early in time (~500 years) then slowly decreases for the remaining simulation time. This decrease in saturation can primarily be attributed to brine consumption by iron corrosion and radiolysis of brine.

Scenarios that include an E1 intrusion (S2-BF, S3-BF, and S6-BF) see a rapid increase in brine saturation at the time of intrusion due to the inflow of Castile brine from the intersected pressurized brine pocket. This rapid increase in brine saturation occurs in the intruded waste panel and the south rest-of-repository where the abandonment of panel closures between panels allows for greater communication.

Scenarios that include an E2 intrusion (S4-BF and S5-BF) see an increase in brine saturation compared with the undisturbed case. Statistics for brine saturation are presented in Table 4-3.

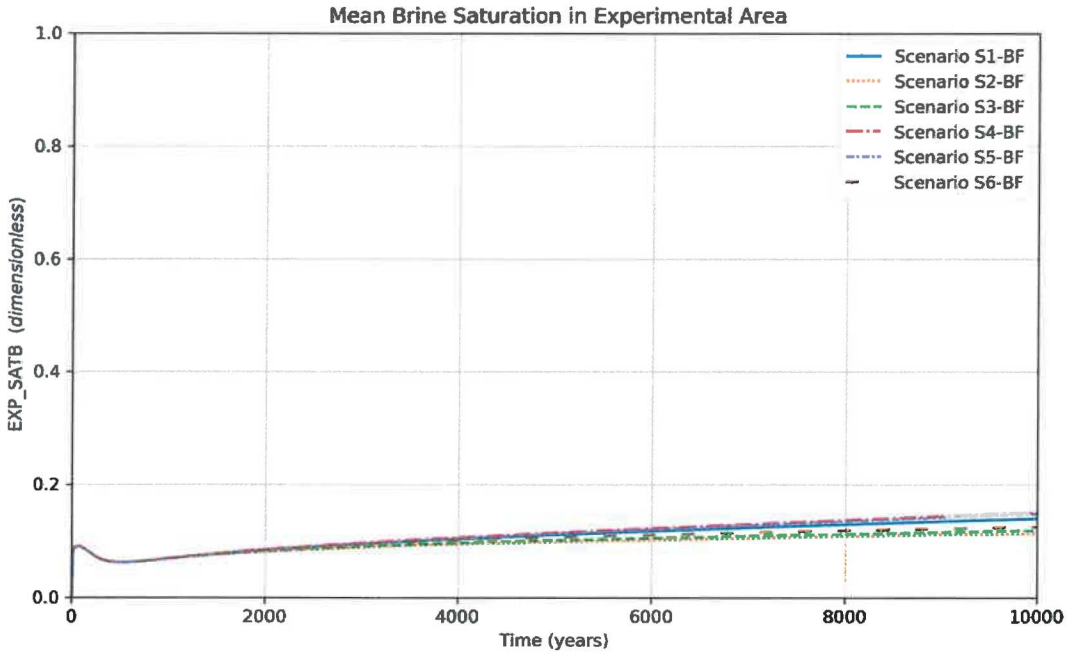

Figure 4-6: Means of Brine Saturation in the Experimental Area

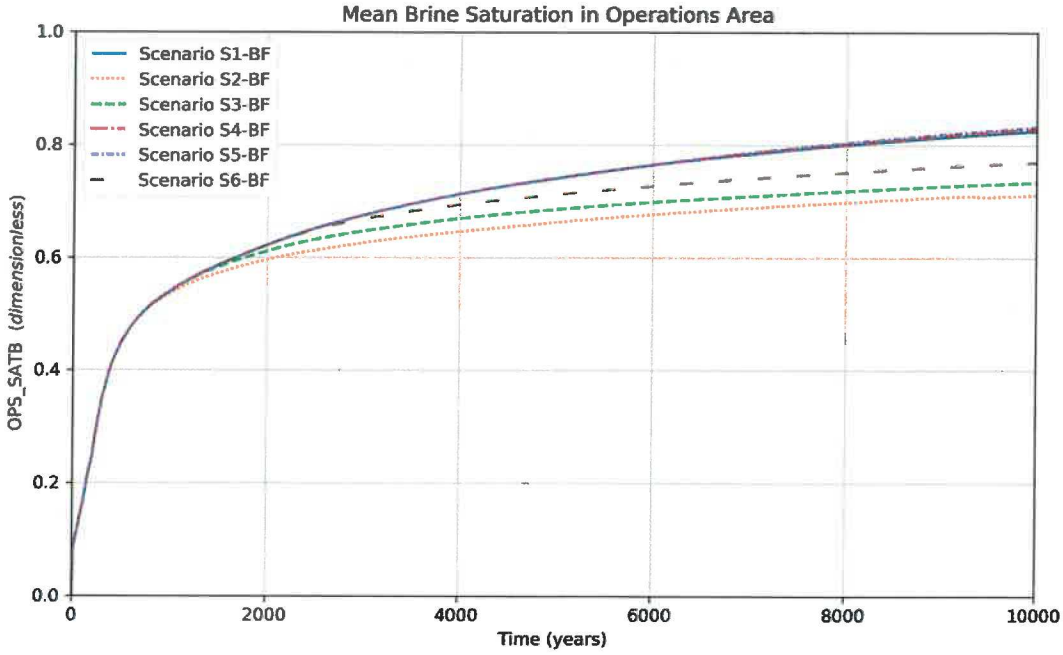

Figure 4-7: Means of Brine Saturation in the Operations Area

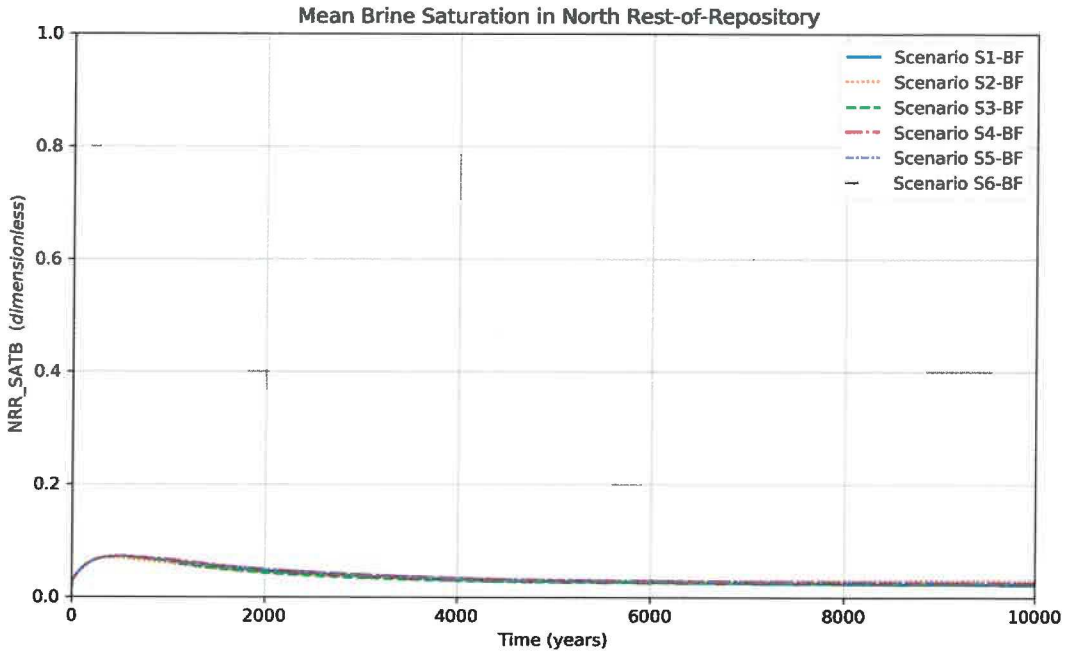

Figure 4-8: Means of Brine Saturation in the North Rest-of-Repository

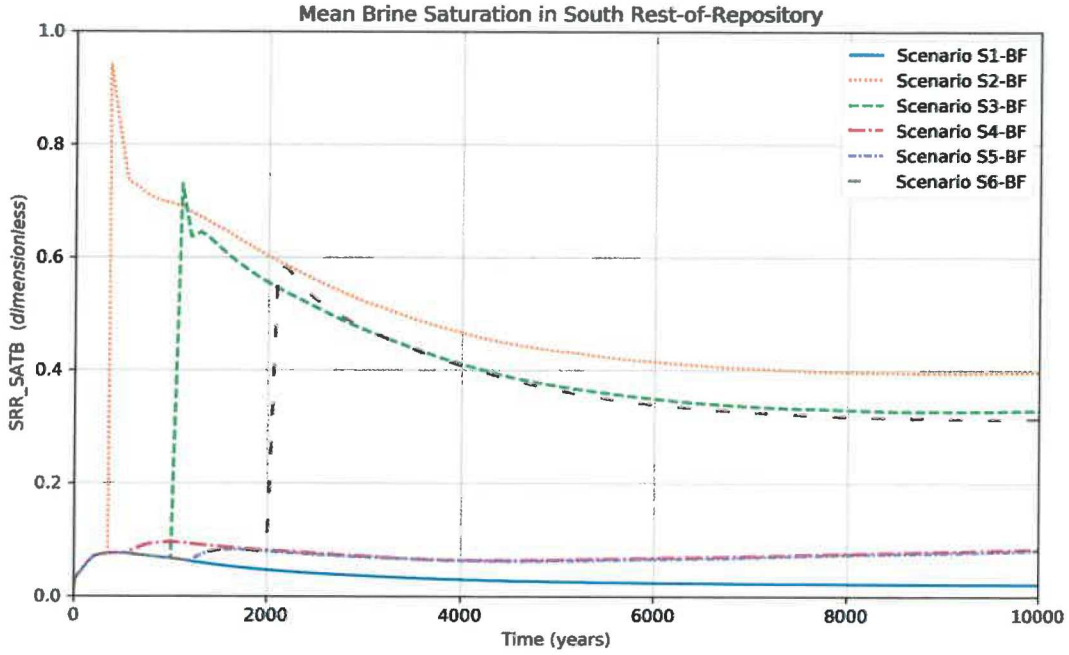

Figure 4-9: Means of Brine Saturation in the South Rest-of-Repository

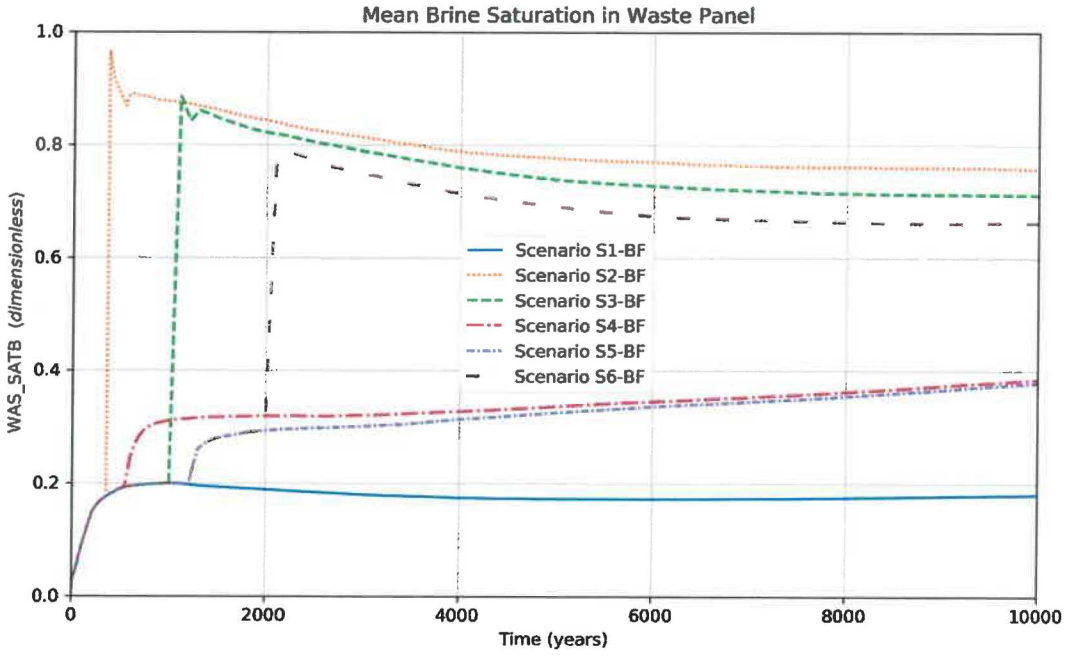

Figure 4-10: Means of Brine Saturation in the Waste Panel

Table 4-3: Brine Saturation Statistics on Overall Means for NEPA20

Quantity (units)	Description	Scenario	Time-Averaged Mean Saturation[1]	Maximum Saturation[2]
EXP_SATB (dimensionless)	Brine Saturation in Experimental Area	S1-BF	1.08E-01	1.40E-01
		S2-BF	9.44E-02	1.12E-01
		S3-BF	9.80E-02	1.19E-01
		S4-BF	1.11E-01	1.50E-01
		S5-BF	1.10E-01	1.49E-01
		S6-BF	1.02E-01	1.25E-01
OPS_ SATB (dimensionless)	Brine Saturation in Operations Area	S1-BF	7.00E-01	8.25E-01
		S2-BF	6.32E-01	7.10E-01
		S3-BF	6.50E-01	7.33E-01
		S4-BF	7.00E-01	8.28E-01
		S5-BF	7.01E-01	8.32E-01
		S6-BF	6.73E-01	7.69E-01
NRR_ SATB (dimensionless)	Brine Saturation in North Rest-of-Repository	S1-BF	3.48E-02	7.17E-02
		S2-BF	3.63E-02	7.00E-02
		S3-BF	3.41E-02	7.16E-02
		S4-BF	3.69E-02	7.17E-02
		S5-BF	3.73E-02	7.17E-02
		S6-BF	3.40E-02	7.16E-02
SRR_ SATB (dimensionless)	Brine Saturation in South Rest-of-Repository	S1-BF	3.39E-02	7.57E-02
		S2-BF	4.67E-01	9.39E-01
		S3-BF	3.69E-01	7.30E-01
		S4-BF	7.32E-02	9.48E-02
		S5-BF	7.02E-02	8.23E-02
		S6-BF	3.10E-01	5.86E-01
WAS_ SATB (dimensionless)	Brine Saturation in Waste Panel	S1-BF	1.78E-01	2.00E-01
		S2-BF	7.70E-01	9.66E-01
		S3-BF	6.91E-01	8.85E-01
		S4-BF	3.29E-01	3.84E-01
		S5-BF	3.11E-01	3.78E-01
		S6-BF	5.94E-01	7.88E-01

Notes:
1 Calculated as the function average (integrated) over the time interval (0-10,000 y) for the overall means
2 Calculated as the function maximum over the time interval (0-10,000 y) for the overall means

4.2.3 Gas Saturation

Gas saturation results are not explicitly provided herein, but are inferred from the brine saturation results presented in Section 4.2.2, with gas saturation equal to one minus the brine saturation.

4.2.4 Gas Generation

In WIPP PA, gas is generated from three processes; iron corrosion, cellulose biodegradation, and radiolysis of brine. Figure 4-11 through Figure 4-16 show the cumulative gas generated from each process as well as the sum from all processes. Gas generation is increased when more brine enters the repository, with iron corrosion and brine radiolysis having larger dependencies on brine saturations than cellulose biodegradation. Following that relationship, disturbed scenarios (S2-BF through S6-BF) show more gas generated than the undisturbed scenario. Scenarios with E1 intrusions show more gas generation than scenarios with only E2 intrusions due to the increased brine saturation resulting from intrusion into Castile brine. Statistics for gas generation are given in Table 4-4.

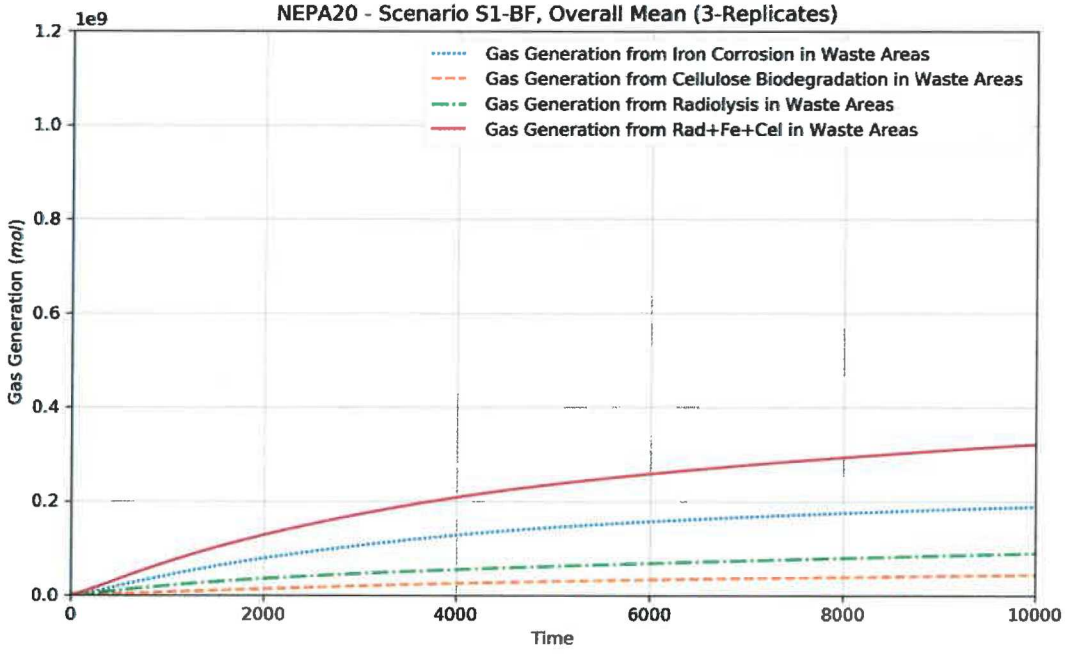

Figure 4-11: Moles of Gas Generated by All Sources, Scenario S1-BF

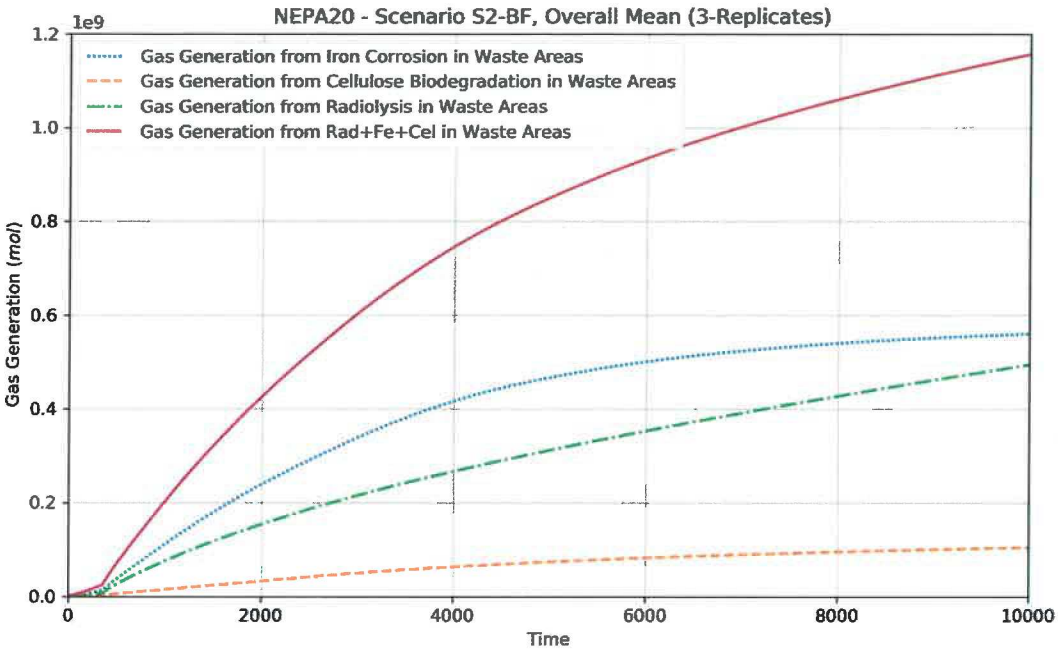

Figure 4-12: Moles of Gas Generated by All Sources, Scenario S2-BF

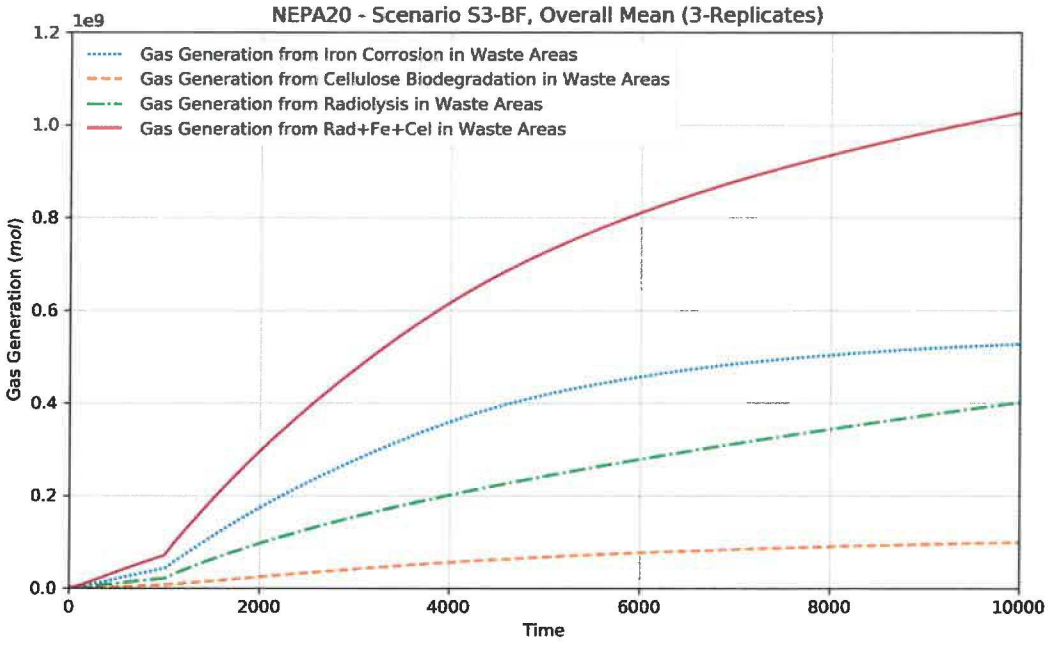

Figure 4-13: Moles of Gas Generated by All Sources, Scenario S3-BF

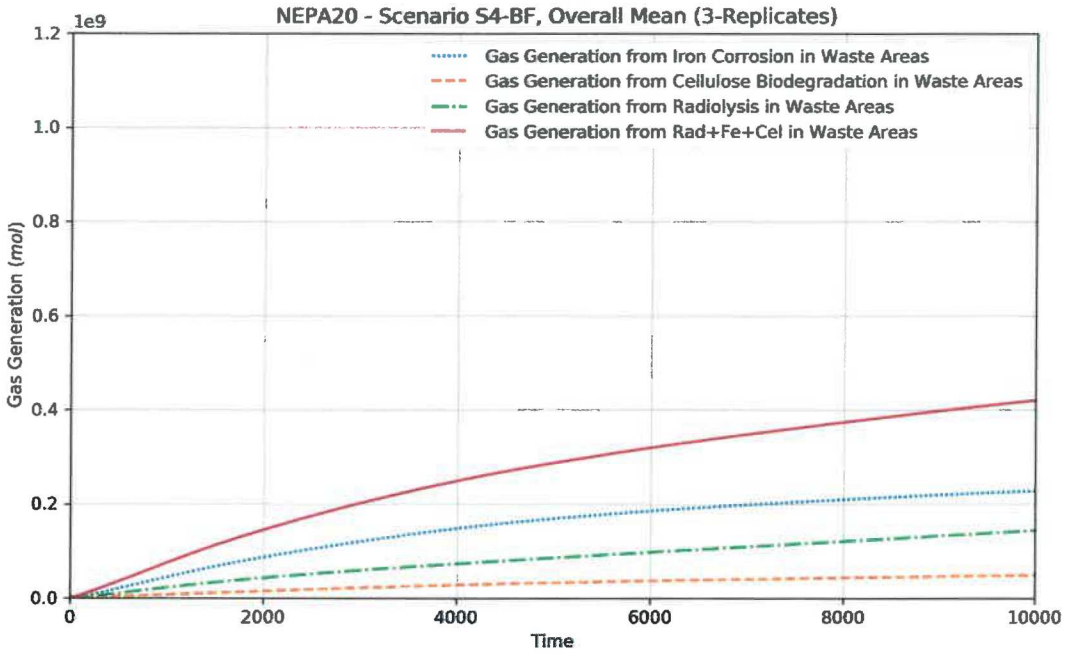

Figure 4-14: Moles of Gas Generated by All Sources, Scenario S4-BF

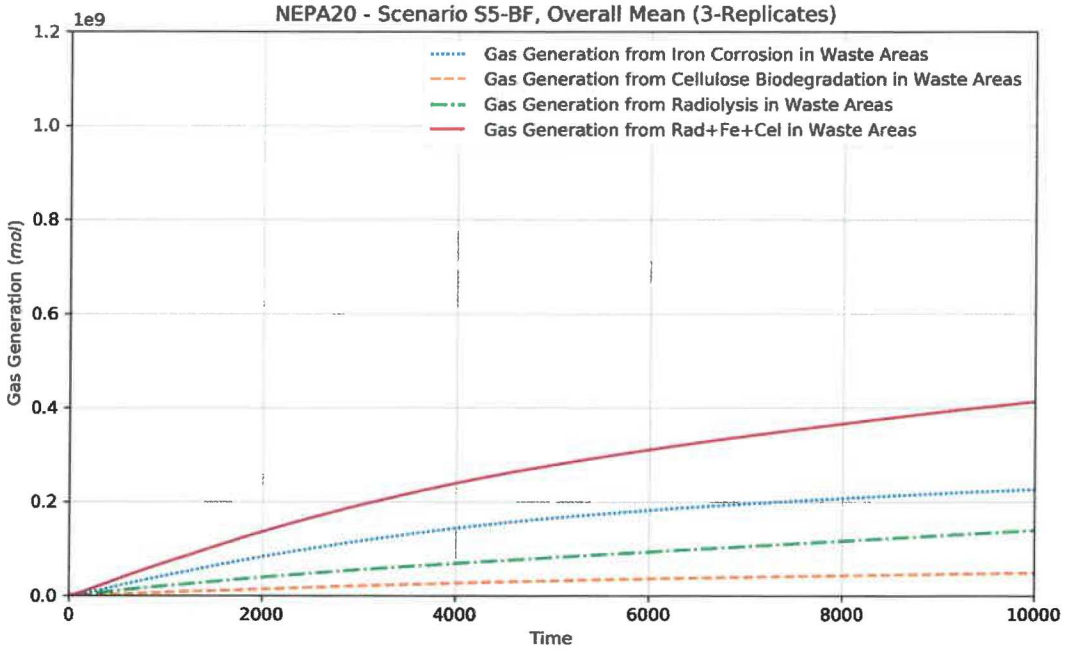

Figure 4-15: Moles of Gas Generated by All Sources, Scenario S5-BF

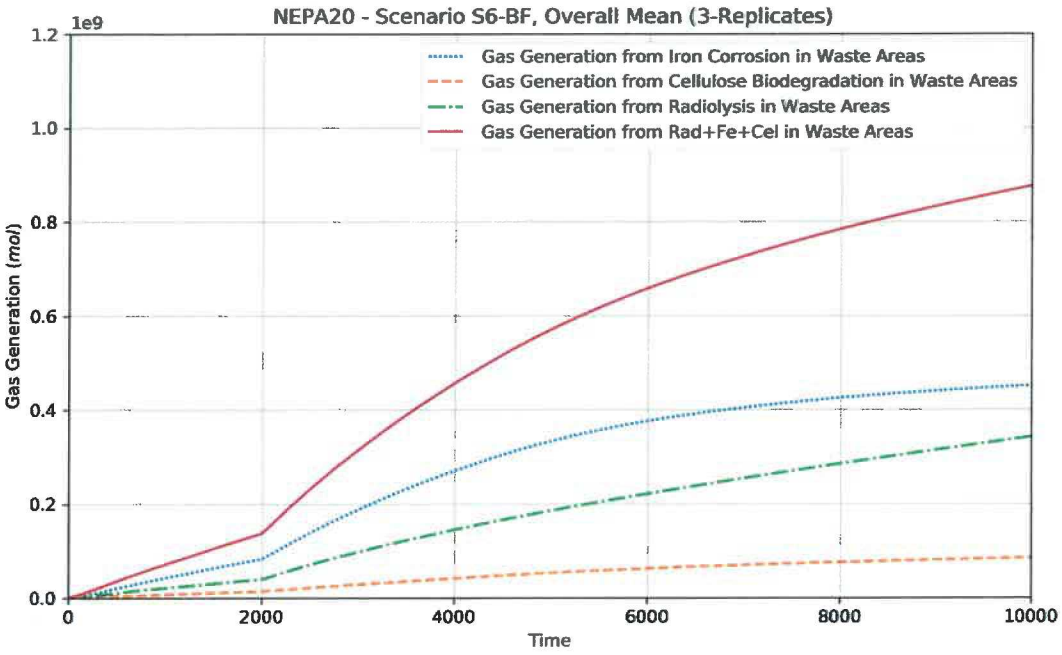

Figure 4-16: Moles of Gas Generated by All Sources, Scenario S6-BF

Table 4-4: Statistics for Overall Mean Gas Generation for NEPA20

Quantity (units)	Description	Scenario	Time-Averaged Mean Moles of Gas Generated[1]	Maximum Moles of Gas Generated[2]
GASMOL_T (mol)	Gas Generation from Corrosion and Biodegradation in Waste Areas	S1-BF	1.54E+08	2.32E+08
		S2-BF	4.62E+08	6.64E+08
		S3-BF	4.09E+08	6.26E+08
		S4-BF	1.79E+08	2.76E+08
		S5-BF	1.75E+08	2.74E+08
		S6-BF	3.27E+08	5.35E+08
FEMOL_T (mol)	Gas Generation from Iron Corrosion in Waste Areas	S1-BF	1.28E+08	1.89E+08
		S2-BF	3.97E+08	5.60E+08
		S3-BF	3.51E+08	5.27E+08
		S4-BF	1.50E+08	2.28E+08
		S5-BF	1.47E+08	2.26E+08
		S6-BF	2.80E+08	4.51E+08
CELMOL_T (mol)	Gas Generation from Cellulose Biodegradation in Waste Areas	S1-BF	2.61E+07	4.30E+07
		S2-BF	6.46E+07	1.04E+08
		S3-BF	5.86E+07	9.88E+07
		S4-BF	2.88E+07	4.82E+07
		S5-BF	2.83E+07	4.77E+07
		S6-BF	4.67E+07	8.40E+07
ALL_HRDC (mol)	Gas Generation from Radiolysis in Waste Areas	S1-BF	5.74E+07	8.96E+07
		S2-BF	2.90E+08	4.95E+08
		S3-BF	2.23E+08	4.02E+08
		S4-BF	8.18E+07	1.44E+08
		S5-BF	7.79E+07	1.39E+08
		S6-BF	1.74E+08	3.42E+08
ALL_HTTC (mol)	Gas Generation from All Processes in Waste Areas	S1-BF	2.11E+08	3.21E+08
		S2-BF	7.51E+08	1.16E+09
		S3-BF	6.31E+08	1.03E+09
		S4-BF	2.60E+08	4.20E+08
		S5-BF	2.53E+08	4.12E+08
		S6-BF	5.00E+08	8.75E+08

Notes:
1 Calculated as the function average (integrated) over the time interval (0-10,000 y) for the overall means (3 replicates)
2 Calculated as the function maximum over the time interval (0-10,000 y) for the overall means (3 replicates)

4.2.5 Brine Flow up the Borehole

Figure 4-17 shows the mean brine flow up the borehole for the six BRAGFLO scenarios. Brine flow up the borehole is the primary pathway for releases to the Culebra. Scenarios with an E1 intrusion (S2-BF, S3-BF, S6-BF) show a relatively large amount of brine flow up the borehole. The E2 intrusion scenarios (S4-BF, S5-BF) show relatively less brine flow up the borehole.

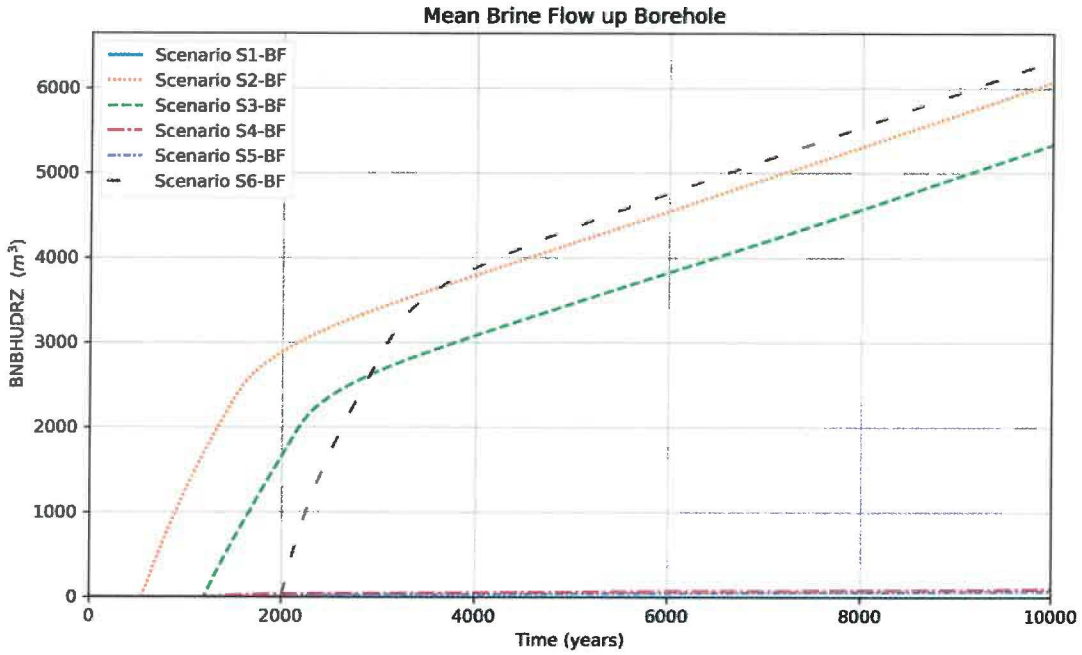

Figure 4-17: Brine Flow up the Borehole Means

Table 4-5: Statistics for Overall Mean Brine Flow up the Borehole for NEPA20

Quantity (units)	Description	Scenario	Time-Averaged Mean Brine Flow[1]	Maximum Brine Flow[2]
BNBHUDRZ (m^3)	Brine Flow up Borehole	S1-BF	9.33E-06	2.82E-05
		S2-BF	3.88E+03	6.07E+03
		S3-BF	3.11E+03	5.34E+03
		S4-BF	5.02E+01	9.05E+01
		S5-BF	3.61E+01	6.97E+01
		S6-BF	3.60E+03	6.33E+03

Notes:
1 Calculated as the function average (integrated) over the time interval (0-10,000 y) for the overall mean
2 Calculated as the function maximum over the time interval (0-10,000 y) for the overall mean

5 Direct Brine Release: BRAGFLO_DBR Calculations

This section describes the direct brine release (DBR) calculations for the NEPA20 analysis. For more information on the development, history, and implementation details of the DBR model, see Stoezel (1996) and Bethune (2019).

5.1 Introduction

If the WIPP repository were to be penetrated by a borehole while under conditions of sufficient repository brine pressure and saturation, brine could migrate up through the intruding borehole to reach the land surface. Such an event is defined as a direct brine release (DBR). The BRAGFLO-DBR code is used to evaluate DBR volumes for a suite of 23,400 reference conditions, varying initial repository pressures and saturations produced by the BRAGFLO scenarios, and the intrusion locations and times evaluated in the DBR scenarios (Table 6-2). As for all release mechanisms, there are conservative assumptions built into the DBR volume calculations that result in overestimation of DBR volumes (DOE 2019, Appendix MASS).

The 2-dimensional, rectilinear BRAGFLO_DBR grid explicitly represents individual panels and other specific repository features (Figure 2-4). Initial conditions are mapped from the BRAGFLO grid's waste panel (WP), south rest-of-repository (SROR), and north rest-of-repository (NROR) lumped waste regions, onto the BRAGFLO_DBR grid panels containing the Lower, Middle, and Upper intrusion locations, respectively.

Minimum pressure and saturation conditions must exist within the waste panel for brine to flow to the surface during an intrusion and produce a DBR. Pressure in the intruded waste panel must be great enough to overcome the static pressure exerted by a column of drilling fluid at the repository depth, assumed to be equal to 8 megapascals (MPa). Brine saturation in the intruded waste panel must be above the residual brine saturation of the waste (parameter WAS_AREA:SAT_RBRN).

DBR volumes are multiplied by the mobilized radionuclide concentrations (Section 7) to calculate DBR radionuclide releases (Section 12.2.4). For the NEPA20 analysis, DBR volumes are also used in dose calculations (Section 13).

5.2 Results

The BRAGFLO_DBR average input conditions and output DBR volumes are presented below. Additional statistics are presented for each scenario in Sections 7.2.1 through 7.3.5 and summarized in Section 7.3.6.

Input conditions are postprocessed from the output of the second ALGEBRACDB step of the BRAGFLO_DBR workflow (Bethune 2019). The mean values presented here represent the average conditions encountered by the BRAGFLO_DBR modeled intrusions and are not weighted

to represent repository averages. Summary statistics of the DBR volumes are compiled from the SUMMARIZE output of the BRAGFLO_DBR workflow (Bethune 2019).[6]

5.2.1 DBR Scenario 1 (S1-DBR)

Average repository conditions and output DBR volumes are presented in Table 5-1 for the BRAGFLO_DBR scenario 1 (S1-DBR). Results from the BRAGFLO S1-BF scenario are used as initial conditions representing an undisturbed repository. DBR intrusions for the upper, middle, and lower locations are modeled at times 100, 350, 1,000, 3,000, 5,000, and 10,000 years.

Summary statistics of the initial conditions show that, on average, saturation is highest at the lower intrusion location, and decreases moving from the lower to middle to upper intrusion locations. Pressure is equally high at the lower and middle intrusion locations, and lowest in the upper intrusion location. Correspondingly, release volumes are highest from the lower intrusion and lowest from the upper intrusion location. Overall, release volumes from the S1-DBR scenario are relatively low, with only 2.63% of simulations producing a non-zero DBR, although the maximum release volume was over 80 m^3 brine.

[6] Statistics and plots were generated with Python version 3.7, an open-source computer programming language.

Table 5-1: DBR Scenario 1 (S1-DBR) Input Condition and Output Volume Statistics

Intrusion Location and Time (yr)	Mean Pressure (Pa)	Mean Brine Saturation (-)	Fraction of Vectors with Non-zero Release Volume (%)	Mean non-zero release volume (m^3)	Mean release volume (m^3)	Maximum release volume (m^3)
Lower[a]	**3.88E+06**	**16.70%**	**5.83%**	**12.56**	**0.73**	**80.79**
100	4.83E+05	9.14%	--	--	0.00	0.00
350	1.37E+06	17.64%	--	--	0.00	0.00
1000	3.11E+06	20.00%	3.33%	11.52	0.38	29.64
3000	5.11E+06	18.05%	11.67%	13.27	1.55	75.07
5000	6.03E+06	17.33%	9.33%	12.51	1.17	74.31
10000	7.17E+06	18.05%	10.67%	12.15	1.30	80.79
Middle[a]	**3.88E+06**	**4.61%**	**1.06%**	**3.33**	**0.04**	**39.39**
100	4.82E+05	5.07%	--	--	0.00	0.00
350	1.37E+06	7.53%	--	--	0.00	0.00
1000	3.11E+06	6.69%	1.33%	11.46	0.15	39.39
3000	5.11E+06	3.62%	1.67%	3.39	0.06	15.88
5000	6.02E+06	2.62%	2.00%	0.07	0.00	0.19
10000	7.17E+06	2.16%	1.33%	0.02	0.00	0.10
Upper[a]	**3.55E+06**	**4.54%**	**1.00%**	**0.45**	**0.00**	**5.42**
100	4.76E+05	4.99%	--	--	0.00	0.00
350	1.27E+06	7.01%	--	--	0.00	0.00
1000	2.75E+06	6.46%	--	--	0.00	0.00
3000	4.58E+06	3.71%	2.33%	0.23	0.01	1.57
5000	5.49E+06	2.83%	1.67%	1.12	0.02	5.42
10000	6.72E+06	2.23%	2.00%	0.14	0.00	0.82
OVERALL	**3.77E+06**	**8.62%**	**2.63%**	**9.79**	**0.26**	**80.79**

[a]Mean values averaged over all intrusion times

5.2.2 DBR Scenario 2 (S2-DBR)

Average repository conditions and output DBR volumes are presented in Table 5-2 for the BRAGFLO_DBR scenario 2 (S2-DBR). Results from the BRAGFLO S2-BF scenario are used as initial conditions for DBR calculations associated with a second or subsequent intrusion into the repository, where the prior (E1) intrusion had connected the waste panel to the underlying pressurized Castile brine reservoir at 350 years. DBR intrusions in the upper, middle, and lower locations were modeled at times 550, 750, 2,000, 4,000 and 10,000 years.

Summary statistics of the initial conditions show that, on average, saturation and pressure are highest at the lower intrusion location near the prior E1 intrusion, and decrease moving from the lower to middle to upper intrusion locations. Average pressure is slightly higher at the lower intrusion location than the middle intrusion location, and average pressure in both is substantially

higher than the pressure at the upper intrusion location. Correspondingly, release volumes are highest in the lower intrusion location and lowest in the upper intrusion location. Overall, 44.36% of the S2-DBR scenario intrusions produced a non-zero DBR that was on average 16.58 m^3 in volume.

Table 5-2: DBR Scenario 2 (S2-DBR) Input Condition and Output Volume Statistics

Intrusion Location and Time (yr)	Mean Pressure (Pa)	Mean Brine Saturation (-)	Fraction of Vectors with Non-zero Release Volume (%)	Mean non-zero release volume (m^3)	Mean release volume (m^3)	Maximum release volume (m^3)
Lower[a]	**1.03E+07**	**82.66%**	**70.73%**	**21.25**	**15.03**	**114.17**
550	9.27E+06	86.3%	85.33%	12.20	10.41	35.96
750	1.02E+07	88.4%	87.33%	18.49	16.15	51.88
2000	1.11E+07	84.2%	73.00%	27.67	20.20	90.88
4000	1.07E+07	78.7%	59.33%	27.59	16.37	89.94
10000	1.00E+07	75.6%	48.67%	24.67	12.01	114.17
Middle[a]	**1.02E+07**	**57.99%**	**60.47%**	**11.63**	**7.03**	**82.33**
550	9.25E+06	72.7%	84.00%	12.38	10.40	42.39
750	1.02E+07	71.0%	85.67%	12.50	10.71	51.94
2000	1.11E+07	60.1%	65.00%	13.94	9.06	82.33
4000	1.07E+07	46.6%	43.33%	8.56	3.71	73.22
10000	9.98E+06	39.6%	24.33%	5.21	1.27	66.38
Upper[a]	**6.71E+06**	**4.74%**	**1.87%**	**0.36**	**0.01**	**5.34**
550	2.71E+06	6.8%	--	--	0.00	0.00
750	3.88E+06	6.4%	--	--	0.00	0.00
2000	7.73E+06	4.3%	4.33%	0.25	0.01	1.68
4000	9.30E+06	3.3%	2.67%	0.83	0.02	5.34
10000	9.90E+06	2.9%	2.33%	0.02	0.00	0.10
OVERALL	**9.07E+06**	**48.47%**	**44.36%**	**16.58**	**7.35**	**114.17**

[a]Mean values averaged over all intrusion times

5.2.3 DBR Scenario 3 (S3-DBR)

Average repository conditions and output DBR volumes are presented in Table 5-3 for the BRAGFLO_DBR scenario 3 (S3-DBR). Results from the BRAGFLO S3-BF scenario are used as initial conditions for DBR calculations associated with a second or subsequent intrusion into the repository, where the prior (E1) intrusion had connected the waste panel to the underlying pressurized Castile brine reservoir at 1000 years. DBR intrusions in the upper, middle, and lower locations are modeled at 1200, 1400, 3,000, 5,000 and 10,000 years.

Summary statistics of the initial conditions show that, on average, saturation and pressure are highest at the lower intrusion location near the prior E1 intrusion, and decrease moving from the

lower to middle to upper intrusion locations. Correspondingly, release volumes are highest at the lower intrusion location and lowest in the upper intrusion location. Overall, 37.07% of the S3-DBR scenario intrusions produced a non-zero DBR that was on average 12.21 m^3 in volume.

Table 5-3: DBR Scenario 3 (S3-DBR) Input Condition and Output Volume Statistics

Intrusion Location and Time (yr)	Mean Pressure (Pa)	Mean Brine Saturation (-)	Fraction of Vectors with Non-zero Release Volume (%)	Mean non-zero release volume (m^3)	Mean release volume (m^3)	Maximum release volume (m^3)
Lower[a]	**9.57E+06**	**78.70%**	**62.87%**	**16.19**	**10.18**	**85.17**
1200	9.44E+06	84.22%	87.33%	10.61	9.26	34.61
1400	9.10E+06	85.41%	74.00%	12.82	9.49	39.71
3000	1.00E+07	78.86%	60.00%	22.00	13.20	66.75
5000	9.86E+06	73.86%	51.33%	21.33	10.95	77.32
10000	9.42E+06	71.15%	41.67%	19.18	7.99	85.17
Middle[a]	**9.55E+06**	**48.82%**	**46.53%**	**7.30**	**3.40**	**47.07**
1200	9.41E+06	63.61%	81.00%	9.68	7.84	33.48
1400	9.07E+06	63.23%	68.00%	7.35	5.00	34.36
3000	1.00E+07	47.12%	42.67%	6.55	2.80	41.82
5000	9.84E+06	37.22%	25.33%	3.76	0.95	47.07
10000	9.40E+06	32.93%	15.67%	2.51	0.39	28.57
Upper[a]	**6.98E+06**	**3.92%**	**1.80%**	**0.17**	**0.00**	**1.57**
1200	4.08E+06	5.70%	0.67%	0.01	0.00	0.02
1400	4.81E+06	5.29%	1.67%	0.26	0.00	1.25
3000	7.81E+06	3.41%	2.67%	0.25	0.01	1.57
5000	8.87E+06	2.71%	2.00%	0.18	0.00	0.61
10000	9.32E+06	2.51%	2.00%	0.02	0.00	0.10
OVERALL	**8.70E+06**	**43.81%**	**37.07%**	**12.21**	**4.53**	**85.17**

[a]Mean values averaged over all intrusion times

5.2.4 DBR Scenario 4 (S4-DBR)

Average repository conditions and output DBR volumes are presented in Table 5-4 for the BRAGFLO_DBR scenario 4 (S4-DBR). Results from the BRAGFLO S4-BF scenario are used as initial conditions to compute DBRs for a second or subsequent intrusion into the repository, where a prior intrusion occurs in the waste panel at 350 years but does not intersect an underlying pressurized Castile brine reservoir. DBR intrusions in the upper, middle, and lower locations are modeled at times 550, 750, 2,000, 4,000 and 10,000 years.

Summary statistics of the initial conditions show that, on average, saturation is highest at the lower intrusion location, and decreases moving from the lower to middle to upper intrusion locations. Pressure is equally high at the lower and middle intrusion locations, and lowest in the upper

intrusion location. Correspondingly, releases are highest from the lower intrusion location. Overall release volumes from the S4-DBR scenario are infrequent and low, with 1.24% of simulations producing a non-zero release averaging 8.14 m^3 of brine.

Table 5-4: DBR Scenario 4 (S4-DBR) Input Condition and Output Volume Statistics

Intrusion Location and Time (yr)	Mean Pressure (Pa)	Mean Brine Saturation (-)	Fraction of Vectors with Non-zero Release Volume (%)	Mean non-zero release volume (m^3)	Mean release volume (m^3)	Maximum release volume (m^3)
Lower[a]	**3.26E+06**	**30.37%**	**2.47%**	**12.15**	**0.30**	**51.73**
550	2.04E+06	19.38%	--	--	0.00	0.00
750	2.18E+06	29.46%	--	--	0.00	0.00
2000	3.36E+06	31.88%	4.33%	11.59	0.50	29.65
4000	4.00E+06	32.74%	4.33%	10.22	0.44	32.11
10000	4.73E+06	38.41%	3.67%	15.08	0.55	51.73
Middle[a]	**3.26E+06**	**7.86%**	**0.47%**	**0.58**	**0.00**	**2.25**
550	2.04E+06	7.53%	--	--	0.00	0.00
750	2.17E+06	9.04%	--	--	0.00	0.00
2000	3.35E+06	8.06%	0.67%	1.82	0.01	2.25
4000	4.00E+06	6.35%	0.67%	0.14	0.00	0.16
10000	4.73E+06	8.31%	1.00%	0.03	0.00	0.09
Upper[a]	**3.41E+06**	**4.97%**	**0.80%**	**0.20**	**0.00**	**1.31**
550	1.83E+06	7.17%	--	--	0.00	0.00
750	2.23E+06	6.94%	--	--	0.00	0.00
2000	3.57E+06	4.90%	2.00%	0.24	0.00	1.31
4000	4.34E+06	3.32%	1.33%	0.24	0.00	0.97
10000	5.08E+06	2.53%	0.67%	0.00	0.00	0.00
OVERALL	**3.31E+06**	**14.40%**	**1.24%**	**8.14**	**0.10**	**51.73**

[a]Mean values averaged over all intrusion times

5.2.5 DBR Scenario 5 (S5-DBR)

Average repository conditions and output DBR volumes are presented in Table 5-5 for the BRAGFLO_DBR scenario 5 (S5-DBR). Results from the BRAGFLO scenario S5-BF are used as initial conditions in the computation of DBR volumes for the case of a second or subsequent intrusion into the repository, where the first intrusion occurs in the waste panel at 1,000 years without intersecting a Castile brine reservoir. DBR intrusions in the upper, middle, and lower locations are modeled at times 1,200, 1,400, 3,000, 5,000 and 10,000 years.

Summary statistics of the initial conditions show that, on average, saturation is highest at the lower intrusion location, and decreases moving from the lower to middle to upper intrusion locations. Pressure is equally high at the lower and middle intrusion locations, and lowest in the upper

intrusion location. Correspondingly, releases are highest from the lower intrusion. Overall, release volumes from the S5-DBR scenario are infrequent and low, with 2.04% of simulations producing a non-zero release averaging 8.42 m^3 of brine.

Table 5-5: DBR Scenario 5 (S5-DBR) Input Condition and Output Volume Statistics

Intrusion Location and Time (yr)	Mean Pressure (Pa)	Mean Brine Saturation (-)	Fraction of Vectors with Non-zero Release Volume (%)	Mean non-zero release volume (m^3)	Mean release volume (m^3)	Maximum release volume (m^3)
Lower[a]	**3.77E+06**	**29.55%**	**4.13%**	**11.41**	**0.47**	**51.66**
1200	3.44E+06	19.85%	4.67%	12.50	0.58	40.34
1400	2.87E+06	27.39%	3.00%	8.69	0.26	22.14
3000	3.68E+06	30.13%	5.00%	12.18	0.61	35.63
5000	4.15E+06	32.55%	4.00%	8.80	0.35	36.19
10000	4.71E+06	37.85%	4.00%	13.84	0.55	51.66
Middle[a]	**3.77E+06**	**7.09%**	**1.20%**	**3.52**	**0.04**	**46.41**
1200	3.44E+06	6.20%	2.00%	9.34	0.19	46.41
1400	2.87E+06	7.85%	1.33%	1.46	0.02	5.82
3000	3.68E+06	6.95%	0.67%	0.61	0.00	0.70
5000	4.14E+06	6.29%	1.00%	0.07	0.00	0.11
10000	4.70E+06	8.14%	1.00%	0.03	0.00	0.09
Upper[a]	**3.97E+06**	**4.28%**	**0.80%**	**0.29**	**0.00**	**1.42**
1200	3.05E+06	6.02%	--	--	0.00	0.00
1400	3.20E+06	5.72%	0.33%	1.30	0.00	1.30
3000	4.02E+06	4.00%	1.67%	0.29	0.00	1.42
5000	4.52E+06	3.06%	1.00%	0.20	0.00	0.59
10000	5.06E+06	2.62%	1.00%	0.04	0.00	0.12
Overall	**3.84E+06**	**13.64%**	**2.04%**	**8.42**	**0.17**	**51.66**

[a]Mean values averaged over all intrusion times

5.2.6 Summary

Consistent with the higher pressure and saturation input, release volumes were highest in scenarios S2-DBR and S3-DBR at the lower and middle intrusion locations, where the hydraulic connection to the prior E1 intrusion is greatest. Pressures in the middle intrusion region are generally equal to or slightly lower than the pressures in the lower intrusion location, while saturations in the middle intrusion location are on average in-between the saturations of the lower and upper location. Maximum DBR output volume from all modeled intrusions is 114.17 m^3 from an S2-DBR intrusion at the lower location.

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6 Solids Volume: CUTTINGS_S and DRSPALL Calculations

This section describes the calculations of the volume of solids releases from the WIPP repository from an intrusion borehole. The PA codes CUTTINGS_S and DRSPALL are used to calculate these volumes which include cuttings, cavings, and spallings. Solids releases are used in dose calculations (Section 13). For more information on the solids release calculation methodology, see Kicker (2019b).

6.1 Introduction

Cuttings and cavings are the solid materials removed from the repository and carried to the surface by the drilling fluid during the process of drilling a borehole. Cuttings are the materials removed directly by the drill bit and cavings are the material eroded from the walls of the borehole by shear stresses from the circulating drill fluid. The volume of cuttings and cavings material removed from a single drilling intrusion into the repository is assumed to be in the shape of a cylinder. CUTTINGS_S calculates the area of the base of this cylinder, and cuttings and cavings results in this section are reported in terms of these areas. The code is run for a specified number of deterministic, hypothetical drilling intrusion scenarios and times (once for each vector). The volumes of cuttings and cavings removed can be calculated by multiplying these areas with the assumed initial repository height, 3.96 m (WIPP PA parameter BLOWOUT:HREPO).

The conceptual model for spallings is documented by Lord et al. (2006, Section 3) and is implemented in the code DRSPALL. A spallings event is a special case of the drilling intrusion in which the repository contains gas at high pressure that causes: (1) localized shear failure of the solid material surrounding the borehole; and (2) entrainment of the failed material into and up the borehole, carried ultimately to the land surface. Calculation of the spallings volume is a two-part procedure. First, DRSPALL calculates the spallings volumes from a single drilling intrusion at four "baseline" values of repository pressure (10, 12, 14, and 14.8 MPa). Next, the code CUTTINGS_S reads the time-dependent pressure for each realization from the BRAGFLO output (Section 4), and linearly interpolates on the DRSPALL output to compute the spalling volume for a given intrusion time.

6.2 Results

Calculated volumes of solid material removed from the repository, including cuttings, cavings, and spallings, are presented in this section.

6.2.1 Cuttings and Cavings

The drill bit diameter is specified to be 0.311150 m (which corresponds to a circular area of 0.0760 m^2) and the cuttings area is constant for all realizations. The variation in cavings area arises primarily from uncertainty in the shear strength of the waste (parameter BOREHOLE:TAUFAIL). Lower shear strengths tend to result in larger cavings releases, and hence larger cuttings and cavings releases (Figure 6-1). In Figure 6-1, the lowest attainable cuttings and cavings release area is 0.0760 m^2, which corresponds to a release due only to cuttings (i.e., a release with zero cavings area). Statistics for cavings area are shown in Table 6-1.

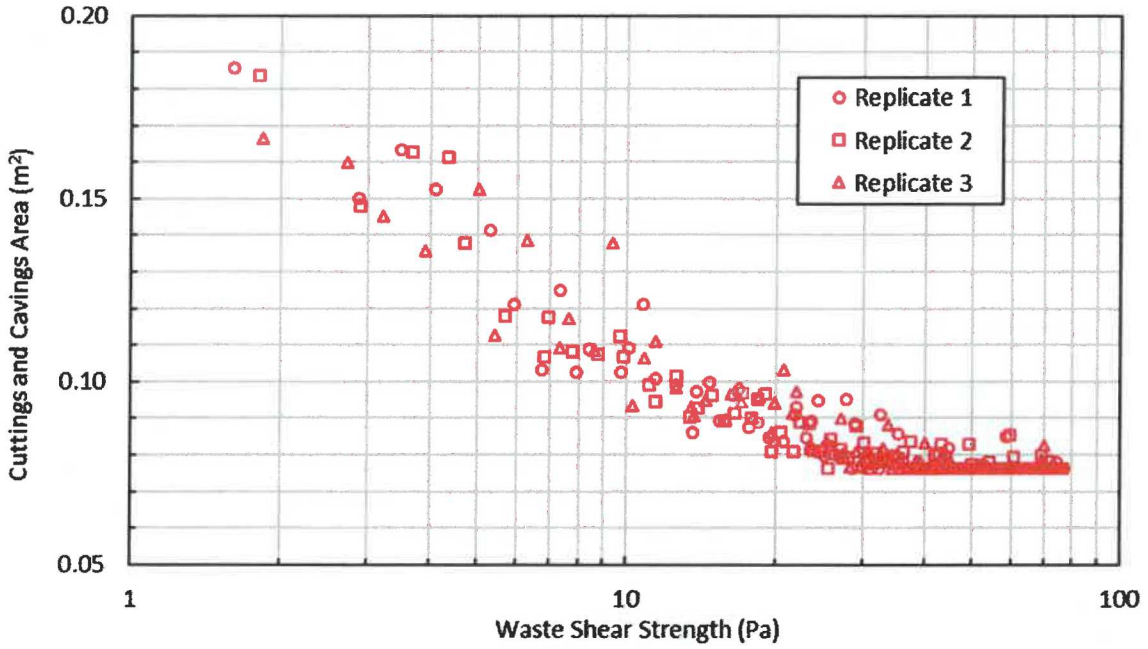

Figure 6-1: Cuttings and Cavings Areas as a Function of Waste Shear Strength

Table 6-1: Cavings Area Statistics for NEPA20 Impact Assessment

Replicate	Mean Cavings Area (m^2)	Max Cavings Area (m^2)	Number of Vectors w/o Cavings
1	0.011	0.110	49
2	0.010	0.107	44
3	0.011	0.090	49

6.2.2 *Spallings*

Spallings releases are calculated by multiplying spallings volumes by the concentration of radionuclides in spallings at the time of intrusion. Spallings volumes are calculated based on pressure conditions in the repository waste areas and are discussed in Section 6.2.2.1. Spallings concentrations are calculated as the average CH-TRU waste concentration (activity/volume) at the time of intrusion and are discussed in Section 6.2.2.2.

6.2.2.1 Spallings Volume

DRSPALL solids release volumes from Kirchner et al. (2015) are used in the NEPA20 analysis. Individual borehole spallings releases are a function of repository conditions (i.e., pressures in waste areas). As for all release mechanisms, there are conservative assumptions built into the spallings volume calculations that result in overestimation of spallings volumes (DOE 2019, Appendix MASS). Intrusion scenarios and times used in the calculation of spallings release volumes correspond to those used in the calculation of direct brine release (DBR) volumes (Section 7) and are shown in Table 6-2.

Spallings volumes are determined by interpolating the spallings volumes calculated by DRSPALL to the repository pressures calculated by BRAGFLO. Summary statistics of spallings volumes for each intrusion scenario are shown in Table 6-3. Results presented in that table are assessed over all three replicates, times, vectors, and drilling locations. As seen in Table 6-3, the maximum spallings volumes obtained are highest in scenarios S2-DBR and S3-DBR, which also have the highest number of realizations that result in a nonzero spallings volume.

Table 6-2: Intrusion Scenarios Used in Calculating Direct Brine and Spallings Releases

DBR/ Spallings Scenario	BRAGFLO Scenario for Initial Conditions	Previous Intrusion Type and Time (year)	Subsequent Intrusion Times – (year)
S1-DBR	S1-BF	None (Undisturbed Repository)	100, 350, 1000, 3000, 5000, 10000
S2-DBR	S2-BF	E1 intrusion at 350	550, 750, 2000, 4000, 10000
S3-DBR	S3-BF	E1 intrusion at 1,000	1200, 1400, 3000, 5000, 10000
S4-DBR	S4-BF	E2 intrusion at 350	550, 750, 2000, 4000, 10000
S5-DBR	S5-BF	E2 intrusion at 1,000	1200, 1400, 3000, 5000, 10000

NOTE:The S*x*-DBR (*x*=1-5) scenario uses the S*x*-BF (Table 4-1) scenario results (waste area pressures and saturations) as initial conditions for a subsequent intrusion at the times given in the last column of Table 6-2. For example, the S1-DBR calculations produce spallings (summarized in Table 6-3) and DBR release volumes (Section 5) for an intrusion into a previously-undisturbed repository at times of 100, 350, 1000, 3000, 5000, and 10000 years.

Table 6-3: Summary Spallings Results by Intrusion Scenario

Scenario	Maximum Volume (m^3)	Mean Nonzero Volume (m^3)	Number of Realizations with Nonzero Spallings Volume
S1-DBR	7.47	0.70	382 (7.1%)
S2-DBR	10.23	0.91	1339 (29.8%)
S3-DBR	10.23	0.78	1171 (26.0%)
S4-DBR	7.47	0.57	134 (3.0%)
S5-DBR	7.47	0.51	185 (4.1%)

Spallings are calculated for three intrusion locations: 1) the Upper Region (which corresponds to the NROR region from BRAGFLO calculations); 2) the Middle Region (SROR); and 3) Lower Region (Waste Panel). Spallings by intrusion location are shown in Table 6-4. Spallings releases in each region are similar, with the highest maximum spallings volumes and highest number of nonzero spallings volumes occurring in the lower intrusion location.

The cumulative frequency of nonzero spallings volumes for the NEPA20 impact assessment (replicates 1, 2, and 3) is shown in Figure 6-2. This figure provides a summary of all spallings data from all scenarios, repository regions, and times. Figure 6-2a considers only those simulations in which nonzero spallings occur, while Figure 6-2b considers all simulations, including those that result in zero spallings volumes.

Summary statistics for spallings volumes from the lower intrusion location for scenario S2-DBR (at 750 years) and S3-DBR (at 1200 years) are shown in Table 6-5 as they are used in later dose

calculations (Section 13). In Table 6-5, the total volume is the sum of the spallings volume and the cuttings and cavings volume. The cuttings and cavings volume is the cuttings and cavings area times the repository height of 3.96 m. For both PA calculations and the dose calculations in the NEPA20 analysis, the solids volume is found by multiplying the total volume by the fractional volume of waste (FVW=0.197, Section 2.2.6.4).

Table 6-4: Summary Spallings Results by Intrusion Location

Intrusion Location	Maximum Volume (m^3)	Mean Nonzero Volume (m^3)	Number of Nonzero Volumes (Percentage of Realizations that Result in a Nonzero Spallings Volume)
Lower Region (Waste Panel)	10.23	0.82	1252 (16.1%)
Middle Region (South ROR)	10.23	0.82	1245 (16.0%)
Upper Region (North ROR)	10.20	0.73	714 (9.2%)

Table 6-5: Summary Cuttings, Cavings, and Spallings Volumes for the Lower Intrusion Location, Scenarios S2-DBR and S3-DBR

Statistic	Intrusion Time (years)	Scenario	Cuttings and Cavings Area (m^2)	Spallings Volume (m^3)	Total Volume (m^3)	Fractional Volume of Waste (-)	Solids Volume (m^3)
Mean	750	S2-DBR	8.67E-02	2.14E-01	5.57E-01	0.197	1.10E-01
Mean	1200	S3-DBR	8.67E-02	3.83E-02	3.82E-01	0.197	7.52E-02
Median	750	S2-DBR	7.74E-02	0.00E+00	3.51E-01	0.197	6.91E-02
Median	1200	S3-DBR	7.74E-02	0.00E+00	3.16E-01	0.197	6.23E-02

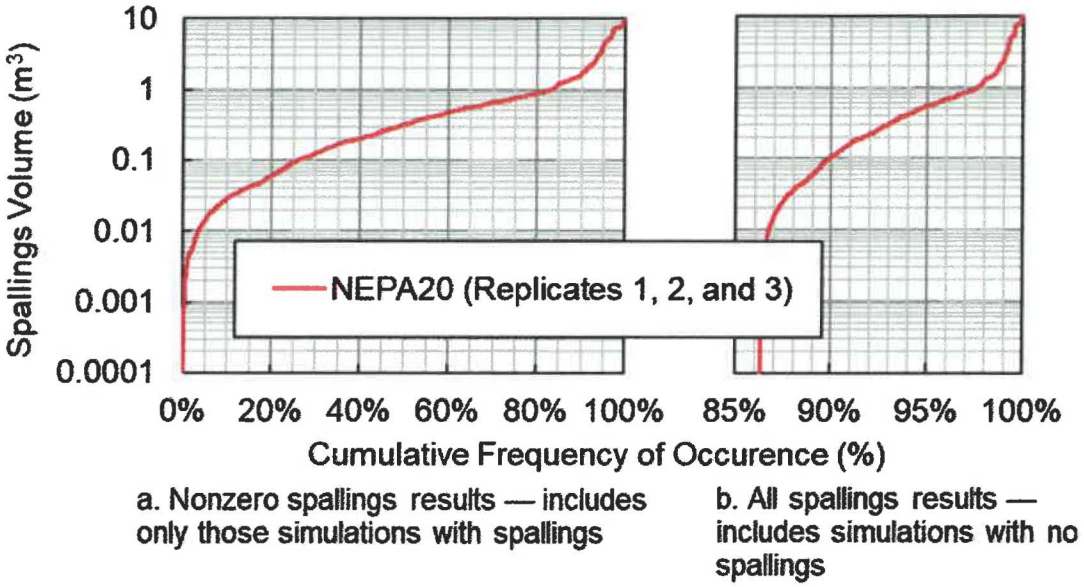

Figure 6-2: Cumulative Frequency of Spallings Volume in NEPA20 Analysis

6.2.2.2 Spallings Concentration

For spallings releases in usual PA calculations, concentrations of radionuclides are calculated by the PRECCDFGF code from EPAUNI output as the waste stream volume-averaged concentration—that same methodology is used to calculate spallings concentrations for dose calculations in the NEPA20 analysis. Spallings concentration (EPA units/m^3) throughout the 10,000-year regulatory period is shown in Figure 6-3. When modeling a drilling intrusion into the repository, there is an uncertainty around which waste stream will be intersected, so cuttings and cavings concentrations for a given intrusion event in usual PA calculations are assumed to depend on random waste stream selection in CCDF release calculations. However, for the primary dose calculations in the NEPA20 analysis, cuttings and cavings concentrations are derived from waste stream concentrations in the same manner as spallings; as a result, all solids in the NEPA20 analysis (cuttings, cavings, and spallings) are assumed to have the same radionuclide concentration at a given time according to Figure 6-3.

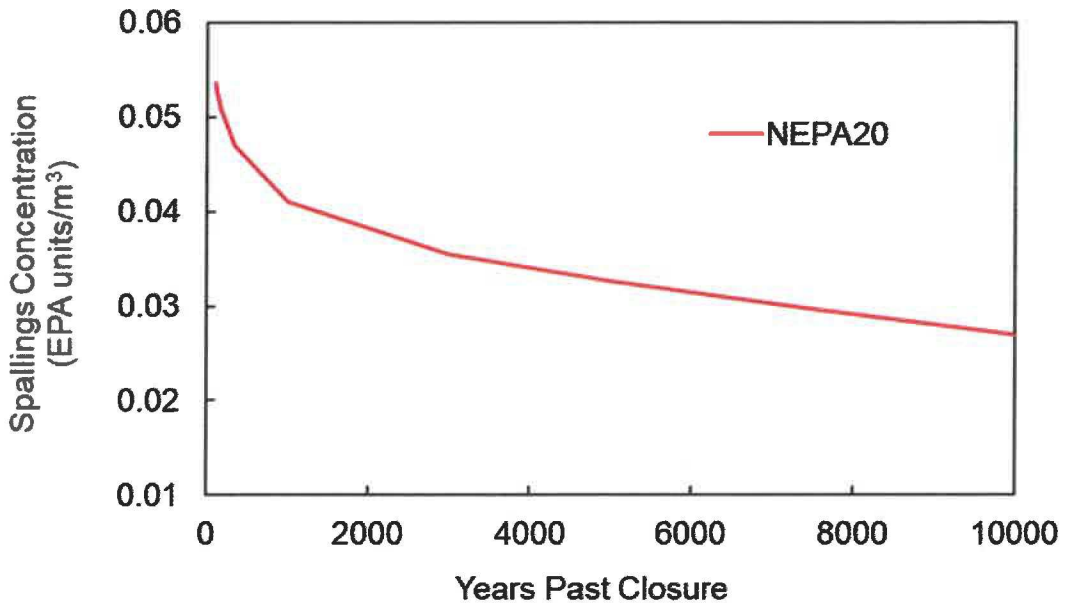

Figure 6-3: Spallings Release Concentration from Closure to 10,000 Years (the same concentrations are applied to cuttings and cavings releases for the NEPA20 dose calculations)

7 Actinide Mobilization: PANEL Calculations

This section discusses the mobile (i.e. aqueous) actinide concentrations in the repository waste panels for the NEPA20 analysis. The calculated mobile actinide concentrations are used in conjunction with direct brine release (DBR) volumes to estimate radionuclide releases due to DBR events. The Salado transport calculations, which also involve actinide concentrations, are discussed in Section 9. For more information on the actinide concentration calculation methodology, see Sarathi (2019).

7.1 Introduction

The code PANEL is used to simulate the radionuclide inventory in the waste panels as it decays and mixes with brine. Specifically, it performs five primary functions:

1. PANEL calculates the radioactive decay and ingrowth of the radionuclide inventory in the waste panels. This calculation influences the amount of inventory available to be released at any time over the 10,000-year post-closure compliance period.
2. PANEL calculates the *total mobilization potential* for each actinide of interest, which is an effective aqueous concentration (solubility) limit that encompasses the maximum amount of dissolved (speciated and complexed) as well as dispersed (i.e. associated with dispersed colloids) actinide in the aqueous phase. The total mobilization potential influences the amount of the inventory of each radionuclide that can be mobilized by brine and thus released via DBR events or aqueous-phase transport mechanisms. These total mobilization potential values are used by both PANEL and NUTS (the Salado transport code) as each calculates aqueous radionuclide concentrations internally. Conservative assumptions associated with mobilization of radionuclides are discussed in DOE (2019, Appendix MASS).
3. PANEL calculates the constant effective solubility fractions of colloids complexed with each actinide, where the complexed colloids are intrinsic colloid, microbial colloid, humic colloid and mineral fragment.
4. PANEL calculates, as a function of time, the aqueous concentration of radionuclides in brine that is in contact with the inventory in the waste panels. Under an assumption of no radionuclide concentration reduction by brine flow, this is a simple saturation-type calculation: the concentration is set to the lesser value of the total mobilization potential and the inventory available at the time divided by the volume of brine in the waste panel.[7] These concentration values directly influence radionuclide releases due to DBR events. For typical WIPP PA calculations, the concentrations are combined with the DBR volumes by the code CCDFGF to calculate DBRs in EPA units (Section 12.2.4). For the NEPA20 analysis, the input needed for dose calculations require DBRs in curies, which are calculated in Section 8.

[7] The same calculation is made by the BRAGFLO code for the calculation of radiolytic gas generation. In the BRAGFLO code, brine volume changes with time while the PANEL code uses a fixed brine volume.

5. PANEL also calculates the long-term discharge of radionuclide-contaminated brine from the repository to the Culebra in the E1E2 scenario (BRAGFLO scenario 6—S6-BF). Discussion of these calculations is deferred to Section 9.

7.2 Results

7.2.1 Inventory and Decay

PANEL models the decay and ingrowth of 30 radionuclides (as listed in Table 2-2) subject to the decay chain reactions in Table 7-1 (Sarathi 2019, Kicker 2019a).

Table 7-1: Decay Chains Modeled in PANEL Code

				^{238}Pu											
				↓											
^{242}Pu	→	^{238}U	→	^{234}U	→	^{230}Th	→	^{226}Ra	→	^{210}Pb	→				
		^{243}Cm													
		↓													
^{243}Am	→	^{239}Pu	→	^{235}U	→	^{231}Pa	→								
						^{244}Cm									
						↓									
^{252}Cf	→	^{248}Cm	→	^{244}Pu	→	^{240}Pu	→	^{236}U	→	^{232}Th	→	^{228}Ra	→		
^{245}Cm	→	^{241}Pu	→	^{241}Am	→	^{237}Np	→	^{233}U	→	^{229}Th	→				
^{147}Pm	→	^{147}Sm	→												
^{137}Cs	→														
^{90}Sr	→														

*The last radioisotope in a chain decays to an isotope that is not tracked in PANEL.

The PANEL code differs slightly from the EPAUNI code (Section 3), which simulates the decay and ingrowth of a subset of these radionuclides for cuttings and cavings and spallings releases. PANEL performs the decay and mass balance calculations on the full set of 30 individual radionuclides. PANEL reports concentrations in terms of 5 "lumped" radionuclides that represent 10 of the 30 radionuclides most significant to potential releases (Table 7-2). A more detailed discussion of the selection and lumping methodology is given in Kicker (2020). PANEL performs this lumping procedure internally and at each time step.

Table 7-2: Lumped and Constituent Radionuclides

Lumped Radionuclide	Constituent Radionuclides
AM241L (or ^{241L}Am)	^{241}Am, ^{241}Pu
PU239L (or ^{239L}Pu)	^{239}Pu, ^{240}Pu, ^{242}Pu
PU238L (or ^{238L}Pu)	^{238}Pu
U234L (or ^{234L}U)	^{234}U, ^{233}U
TH230L (or ^{230L}Th)	^{230}Th, ^{229}Th

Figure 7-1 and Figure 7-2 show the initial inventory in curies (Ci) of the most prevalent radionuclides (by activity) (this is a graphical representation of INVCHD+INVRHD parameters

for the most important radionuclides from Table 2-2). For the NEPA20 analysis, the initial inventory is dominated by ^{241}Am and ^{239}Pu. ^{241}Pu has a short half-life (14 years) and quickly decays into ^{241}Am. ^{238}Pu also has a relatively short half-life (88 years) with respect to the 10,000-year regulatory period considered for typical WIPP PA calculations, and it decays to ^{234}U. ^{137}Cs and ^{90}Sr each have short half-lives (30 and 29 years), and decay to isotopes that are not tracked. ^{244}Cm similarly has a short half-life (18 years) and decays to ^{240}Pu. ^{243}Am has moderate half-life (7370 years) and decays to ^{239}Pu. ^{242}Pu decays slowly with respect to the compliance period (half-life of 390,000 years), and it decays to ^{238}U, which has an extremely long half-life (4.5 billion years) and thus low activity. Thus, when considering both the inventory and the expected timing of release events (between years 100 and 10,000 post-closure), ^{241}Am, ^{239}Pu + ^{240}Pu + ^{242}Pu, and ^{234}U contribute most significantly to radionuclide releases on an activity basis, as is reflected in the lumping scheme.

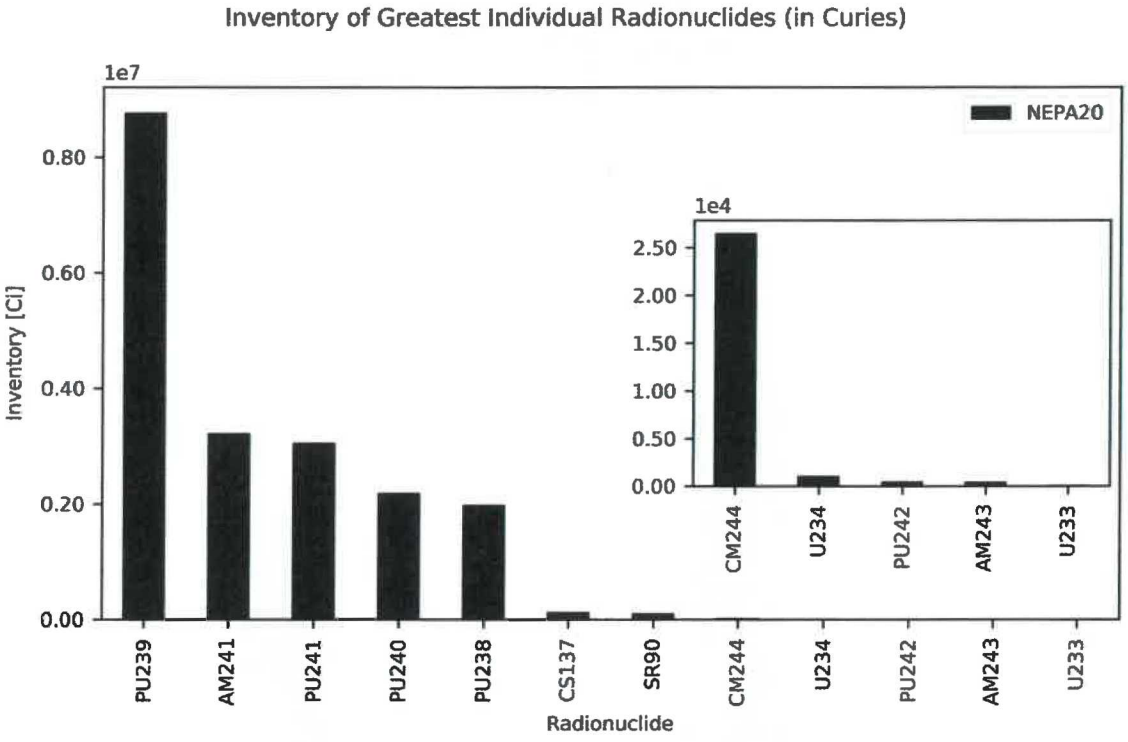

Figure 7-1: Initial Inventory of the Significant Radionuclides in Curies

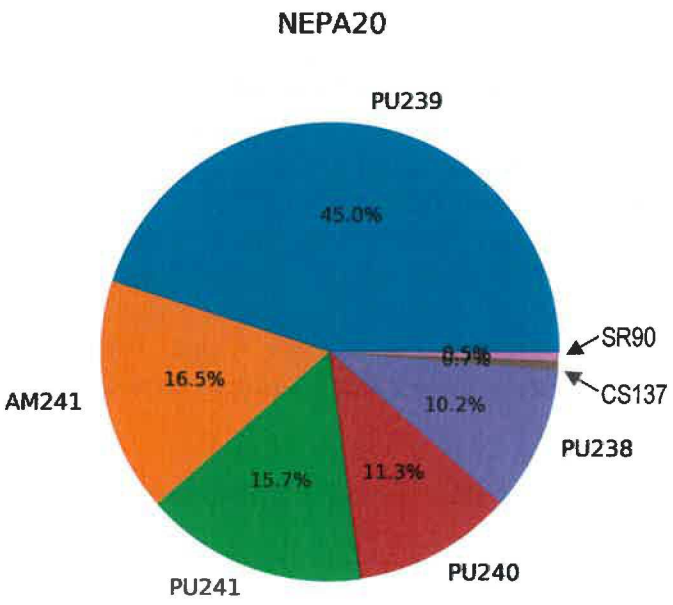

Figure 7-2: Initial Inventory of Radionuclides

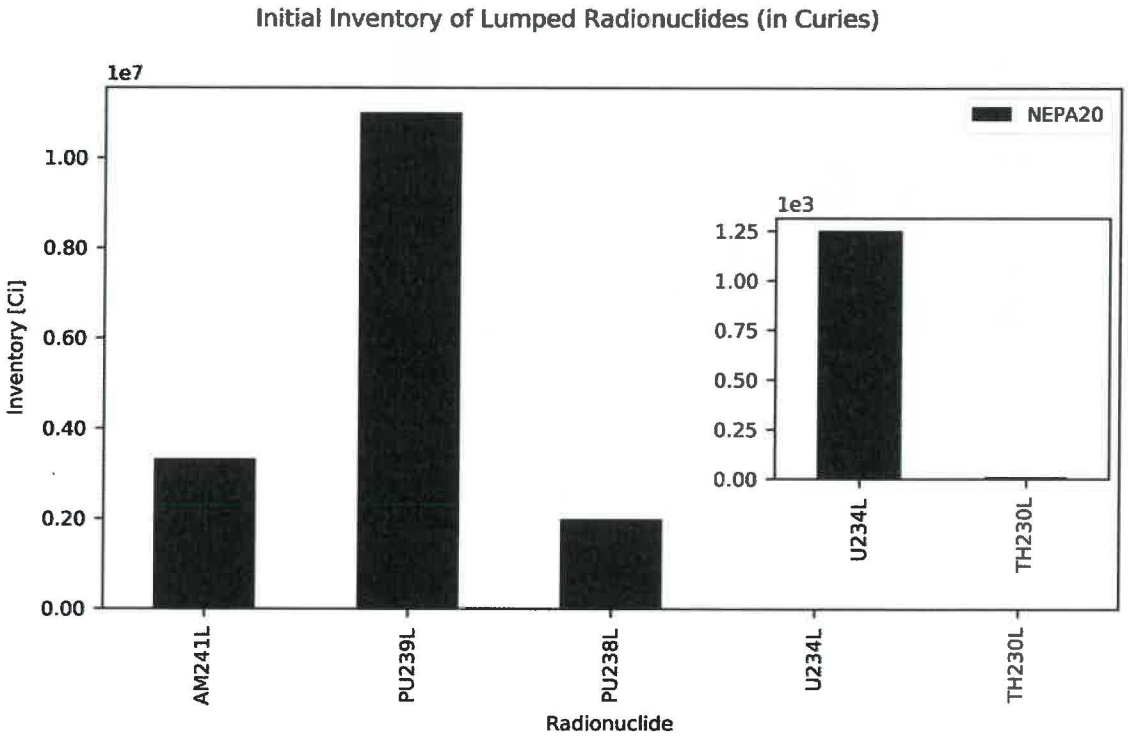

Figure 7-3: Initial Inventory of Lumped Radionuclides in Curies

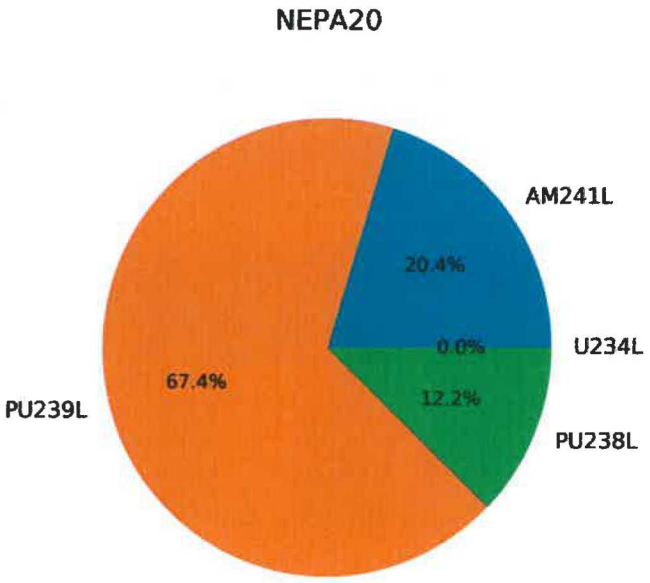

Figure 7-4: Initial Inventory of Lumped Radionuclides

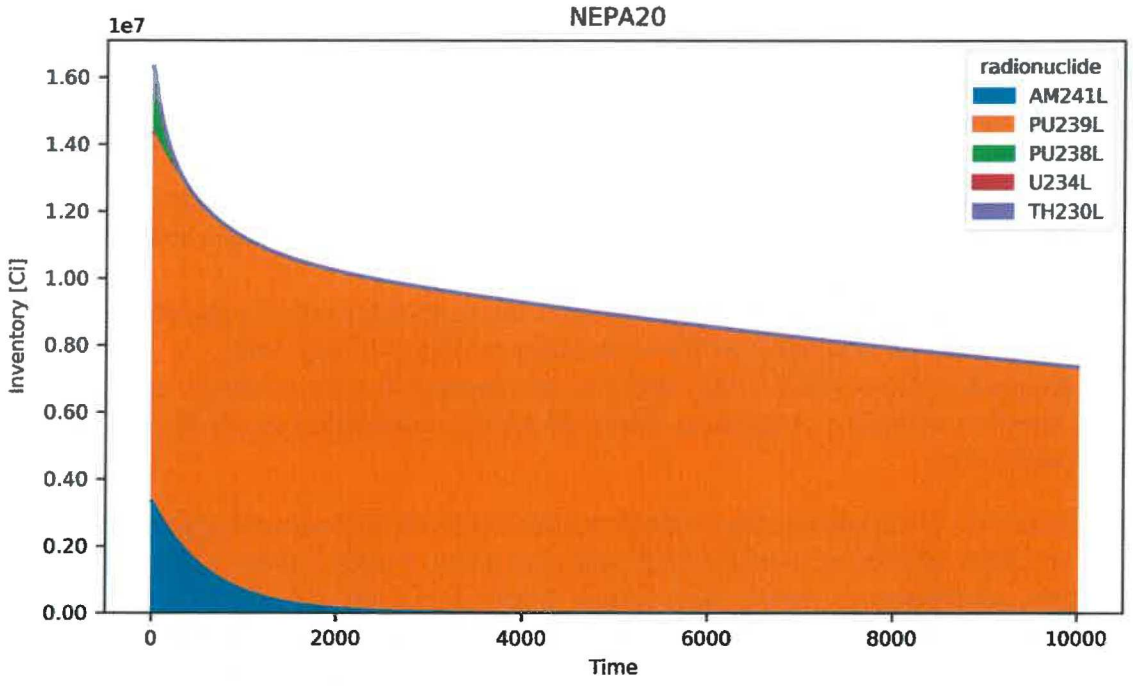

Figure 7-5: Inventory of Lumped Radionuclides (in Ci) Over Time

Figure 7-3 and Figure 7-4 show the initial inventory as represented by the five lumped radionuclides. The same trends are apparent as in the individual isotope inventory; AM241L and PU239L dominate.

Figure 7-5 and Table 7-3 show the total inventory (in Ci) of the decaying lumped radionuclides versus time in the NEPA20 analysis. Initially PU239L and AM241L clearly dominate the inventory by activity. AM241L, with a half-life of 433 years, is a significant contributor to total activity only at early times. PU239L is dominant by activity and moles (Table 7-3) for 10,000 years such that the overall radionuclide concentration in brine is mainly influenced by its remaining inventory.

Table 7-3: Lumped Radionuclide Fractions at Closure and After 10,000 Years.

Lumped radionuclide	At Closure			After 10,000 Years		
	Inventory (Ci)	Inventory (moles)	Mole fraction	Inventory (Ci)	Inventory (moles)	Mole fraction
AM241L	3.32E+06	4.02E+03	5.38E-03	8.85E+00	1.07E-02	2.16E-08
PU239L	1.10E+07	7.41E+05	9.93E-01	7.35E+06	4.95E+05	9.97E-01
PU238L	1.99E+06	4.88E+02	6.54E-04	9.81E-29	2.41E-32	4.86E-38
U234L	1.25E+03	8.55E+02	1.15E-03	1.94E+03	1.33E+03	2.67E-03
TH230L	1.28E+01	2.75E+00	3.69E-06	2.59E+02	5.58E+01	1.13E-04

7.2.2 Solubility Limit/Total Mobilization Potential Calculations

For each vector (i.e., model realization), PANEL calculates the solubility limit of a dissolved actinide and its associated total mobilization potential (the dissolved solubility limit plus the maximum concentrations associated with dispersed colloids) value for five actinides: Am, Pu, U, Th, and Np. These calculated values depend on:

- the predominant source of ionic species and organic compounds in the brine (i.e., from the Salado formation (GWB brine) or from the Castile formation (ERDA-6 brine)) that contacts the waste,
- the reduction/oxidation (red/ox) potential of actinide species in the anoxic brine condition (which determines the (higher or lower) oxidation states of an actinide such as Pu(III) or Pu(IV)),
- the brine volume basis factor (which governs the concentrations of organic ligands which complex with and alter the baseline solubilities of the actinides), and
- an uncertainty factor (SOLVAR) which is the measure that the solubility may differ from the baseline solubility. Additional details about this calculation are given in DOE (2019, Appendix PA).

Baseline solubilities are determined for oxidation state invariant actinide analogs and later applied to the five actinides of interest based on their oxidation states. Figure 7-6 and Figure 7-7 show the input baseline solubilities in Salado and Castile brines that were calculated for the NEPA20 analysis (Domski 2020a). The *n* designation in the figure subtitle *SOLMODn* refers to the valency of the analog actinide, i.e. +III, +IV, +V, or +VI. The x-axis in the figure is the brine volume basis factor, which is the multiple of the minimum brine volume necessary for a DBR event to occur (currently 17,400 m^3, defined with respect to all waste panels in the repository (Section 2.2.6.6)). The brine volume basis factor is used to determine the concentration of organic ligands (acetate, citrate, oxalate, and EDTA) in the contaminated brine (Domski 2020b), as it is assumed that the entire inventory of those organic ligands homogeneously dissolves in the brine. As the brine volume basis factor increases, the concentration of the organic ligands decreases. For SOLMOD3 and SOLMOD5, the dilution of the organic ligand concentrations tends to decrease actinide

solubilities. For SOLMOD4, there is little dependence on the organic ligand concentrations and SOLMOD6 is treated as a constant (Sarathi 2019). An(III) and An(IV) actinides have similar solubility values in both brines while An(V) actinides have solubility values in Castile brine that are 2-3x those for Salado brine.

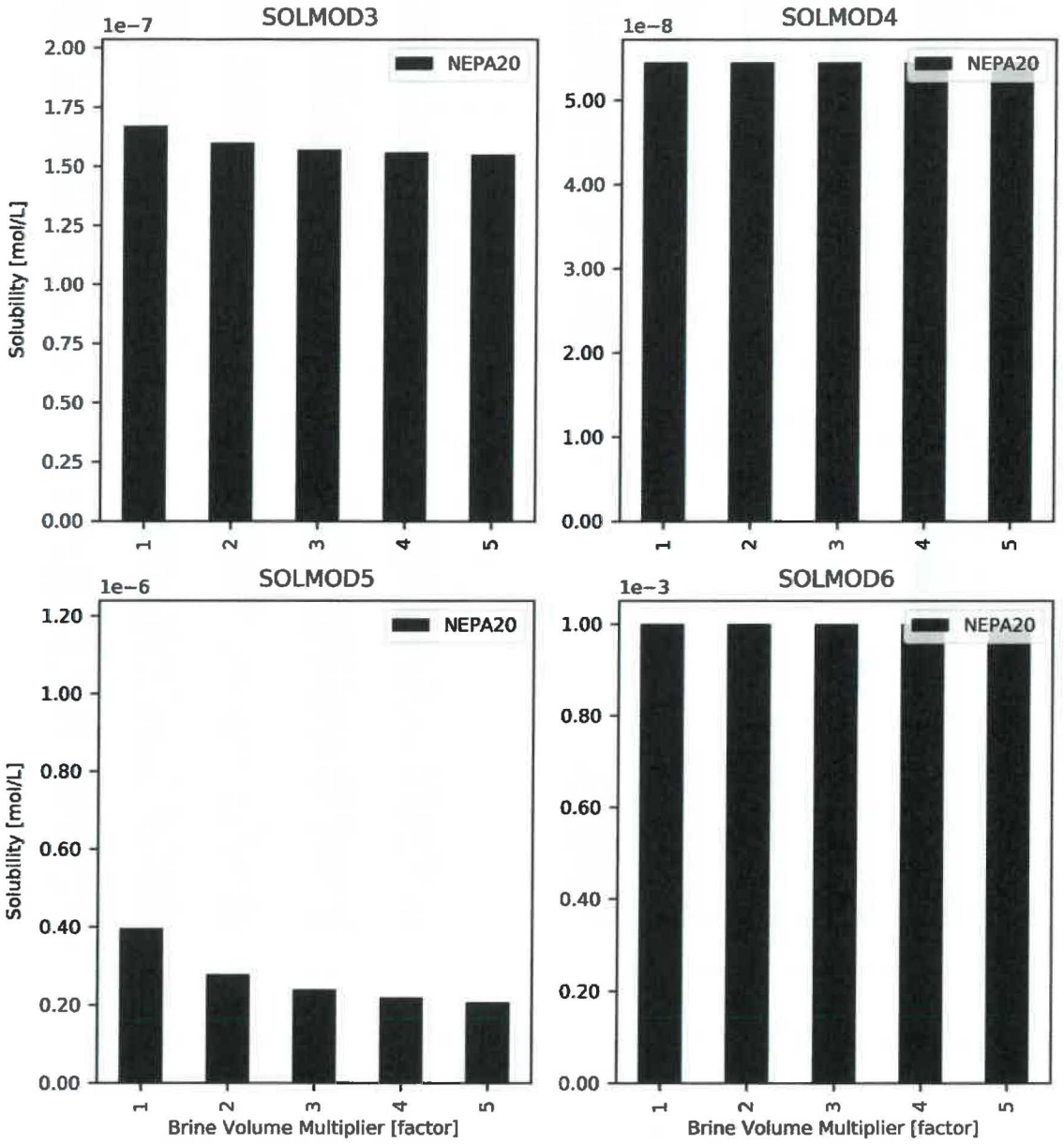

Figure 7-6: Baseline Solubilities for Salado Brine (SOLMOD*n*: *n*=oxidation state number) from Domski (2020b)

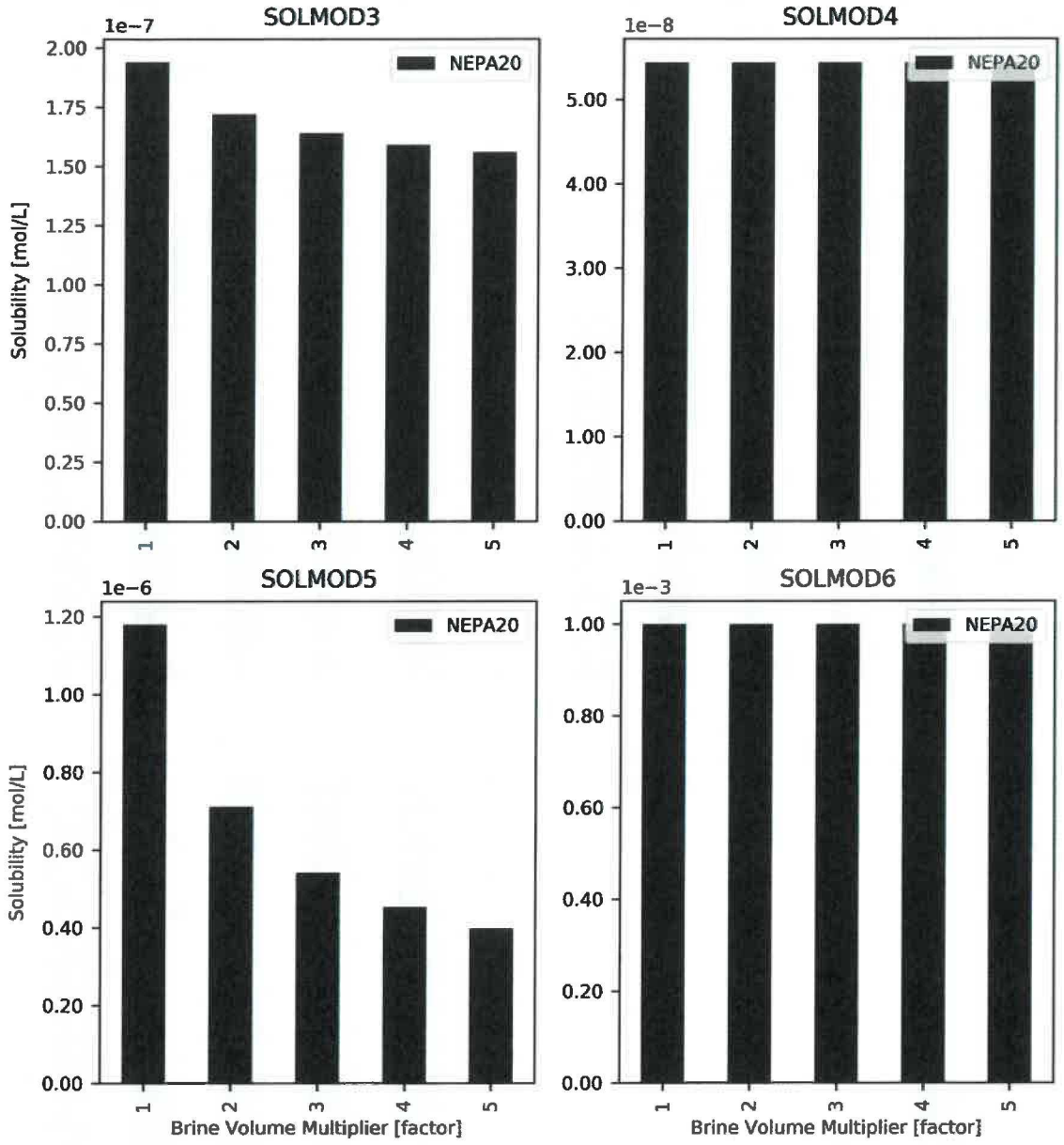

Figure 7-7: Baseline Solubilities for Castile Brine (SOLMOD*n*: *n*=oxidation state number) from Domski (2020b)

The baseline solubility value for each actinide is multiplied by a solubility uncertainty factor (= 10^D, where D is the uncertainty factor (SOLVAR)) to calculate the dissolved solubility limit for the given model realization. The solubility uncertainty modifier parameter distributions are only defined for and applied to actinides in the +III and +IV oxidation states, as described in DOE (2019, Appendix PA).

The dispersed colloid solubility enhancement terms are calculated for the four colloid types: mineral fragment, intrinsic colloid, humic colloid, and microbial colloid. The mineral fragment and intrinsic colloid solubility enhancement terms are constant for both brines. The humic colloid

and microbial colloid solubility enhancement terms are proportional to the dissolved actinide solubility limit but capped at maximum values. The proportionality coefficients are constant and depend on the brine type. The dissolved solubility limit and the four colloidal solubility enhancement terms are summed to calculate the total mobilization potential (Equation 7.1), which is later used to calculate radionuclide concentrations in the brine. DOE (2019, Appendix PA) provides more details of this calculation.

Actinide Total Mobilization Potential =

Dissolved Solubility Limit + Mineral Fragment Associated

+ Intrinsic Colloid Associated + Humic Colloid Associated

+ Microbial Colloid Associated (7.1)

Figure 7-8 shows the distributions of total mobilization potential in Castile brine for five lumped isotopes that depend on their oxidation states. Radionuclide releases are shown to be dominant in the S2-DBR scenario (Section 5.2.6) and these are the releases used in the dose calculation (Section 13). Because only Castile brine is assumed to be present for the S2-DBR scenario (which provides the greatest releases and the releases used in later dose calculations), Salado brine mobilization potential values are omitted here. The total mobilization potential for AM241L and PU239L are set equal to their respective elemental values because ^{241}Am and ^{239}Pu are the dominant isotopes for these lumped radionuclides.

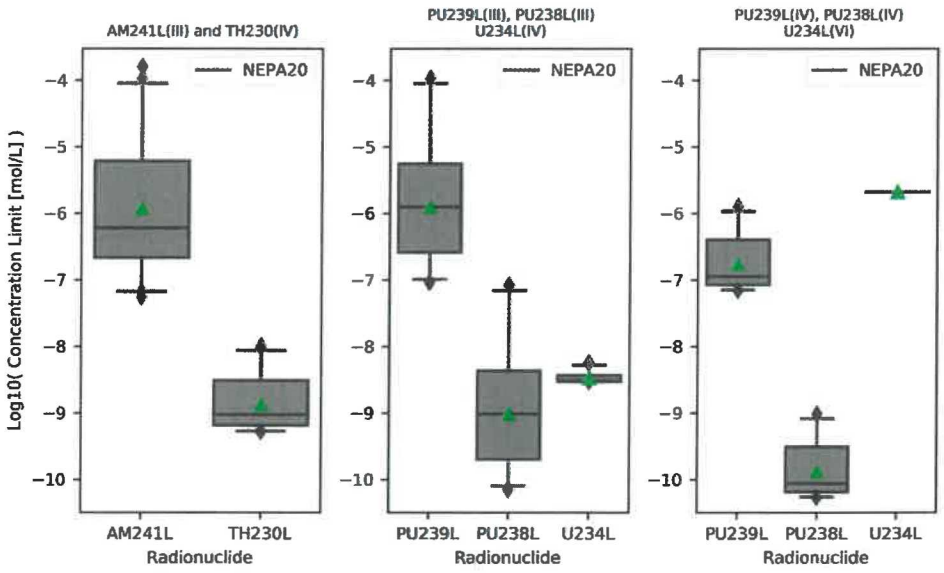

Figure 7-8: Total Mobilization Potential by Lumped Radionuclide, Castile Brine, All Conditions (where the green triangle represents the mean value)

Under the WIPP subsurface reducing conditions, Am is assumed to exist in the +III oxidation state and Th in the +IV state in all model realizations, but Pu is assumed in the +III state in half of the

model realizations and in the +IV state in the other half. Likewise, U can exist in the +IV and +VI oxidation states such that U(IV) is stable in only half of the model realizations and U(VI) in the other half. Figure 7-8 shows total mobilization potentials by lumped radionuclides and their oxidation states. The total mobilization potentials (i.e., aqueous concentration limits) for AM241L and PU239L are larger than those for other lumped radionuclides. SOLMOD3 (+III oxidation state) is larger than SOLMOD4 (+IV oxidation state) (Figure 7-6 and Figure 7-7). This affects the total mobilization potential values for AM241L (only +III oxidation state) more than the PU239L values (50:50 mixtures of +III and +IV oxidation states).

7.2.3 Mobilized Actinide Concentrations in Waste Panel

The PANEL code calculates, as a function of time, the mobilized concentration of each radionuclide in the contaminated brine in the waste panels. This is a simple saturation-type calculation: the concentration is set to the lesser value of the total mobile concentration limit (calculated in Section 7.2.2) and the inventory at the time divided by the volume of brine in the waste panel. These concentration values are used to calculate radionuclide releases due to DBR events. For typical WIPP PA calculations, the concentrations are combined with the DBR volumes by the CCDFGF code to calculate DBRs (Section 12.2.4)). The dose calculations (Section 13) require DBR release in CI for a specific intrusion, as described in Section 8.

Figure 7-9 shows the mean (across the 300 vectors) concentrations of the five lumped isotopes as well as the total activity in the aqueous phase as a function of time, in EPA Units/m^3-brine. The mean total concentration is dominated by AM241L at early times (the brown and blue curves are similar or overlapping), and by PU239L at later times (the brown curve tends toward the orange curve) as the ^{241}Am decays away.

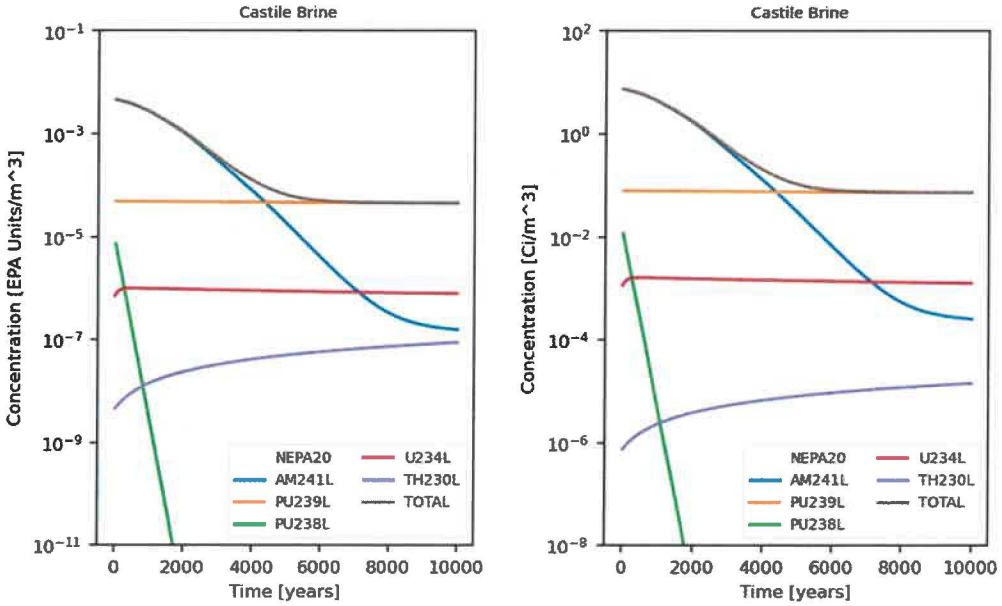

Figure 7-9: Means of Concentrations in Castile Brine vs Time in EPA Units/m^3 (left) and Ci/m^3 (right)

Figure 7-10, Figure 7-11, and Figure 7-12 illustrate the distribution (across vectors) of the concentrations for total activity, AM241L, and PU239L (in EPA units/m^3) in Castile brine at selected snapshots in time (note, the times are not evenly spaced). In Figure 7-10, it is apparent that the mean concentration values (green triangles) are heavily skewed by a few vectors with large concentrations. At early times the top of the distribution decreases with the increasing times, while the mean, median and bottom of the distribution remain similar.

This behavior is due to AM241L (Figure 7-11), which is the primary contributor to the total activity concentration at early times. The large AM241L concentrations at the top of the distribution are not solubility limited values but rather inventory limited values. This initial inventory limit is the same across all vectors. When the solubility limit is larger than the initial inventory limit due to the uncertainty of baseline solubility, the AM241L concentration continuously decreases by its decay. When the solubility limit is smaller than the initial inventory limit, the AM241L concentration remains at the solubility limit while the remaining solid precipitate is not depleted. The median and bottom distribution values are solubility limited values because the solubility limit values are smaller than the initial inventory limit. At later times, the remaining AM241L precipitates begins to deplete, and the concentration distribution shrinks with time as the concentration becomes inventory limited rather than solubility limited in more vectors.

By contrast, the PU239L concentration distributions do not change over time (Figure 7-12) because the initial inventory limit value of PU239L is larger than the solubility-limit values in all vectors. The long half-life of ^{239L}Pu results in consistent concentration values over time, and the mean and median values do not change appreciably. Figure 7-10 through Figure 7-12 show the radionuclide concentrations as calculated by the typical PA methodology, which includes lumping of similar radionuclides. For the purposes of downstream dose calculations, the radionuclides are separated from their lumped forms such that individual radionuclide concentrations are used (Section 8).

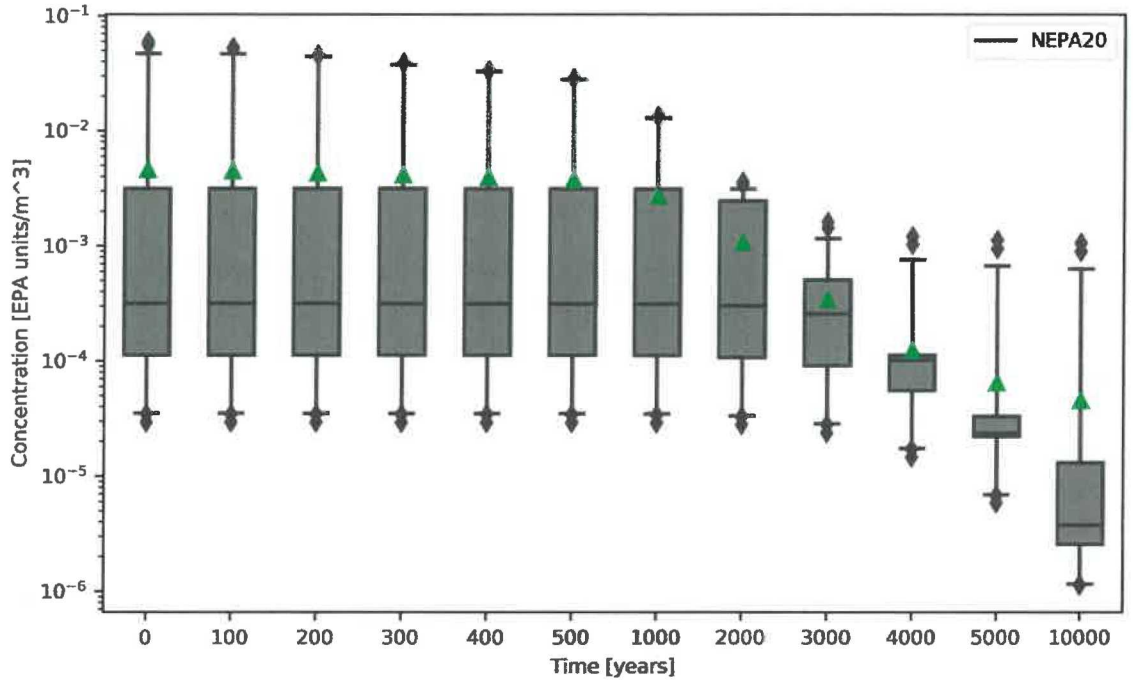

Figure 7-10: Total Concentration vs Time, Castile Brine (where the green triangle represents the mean value)

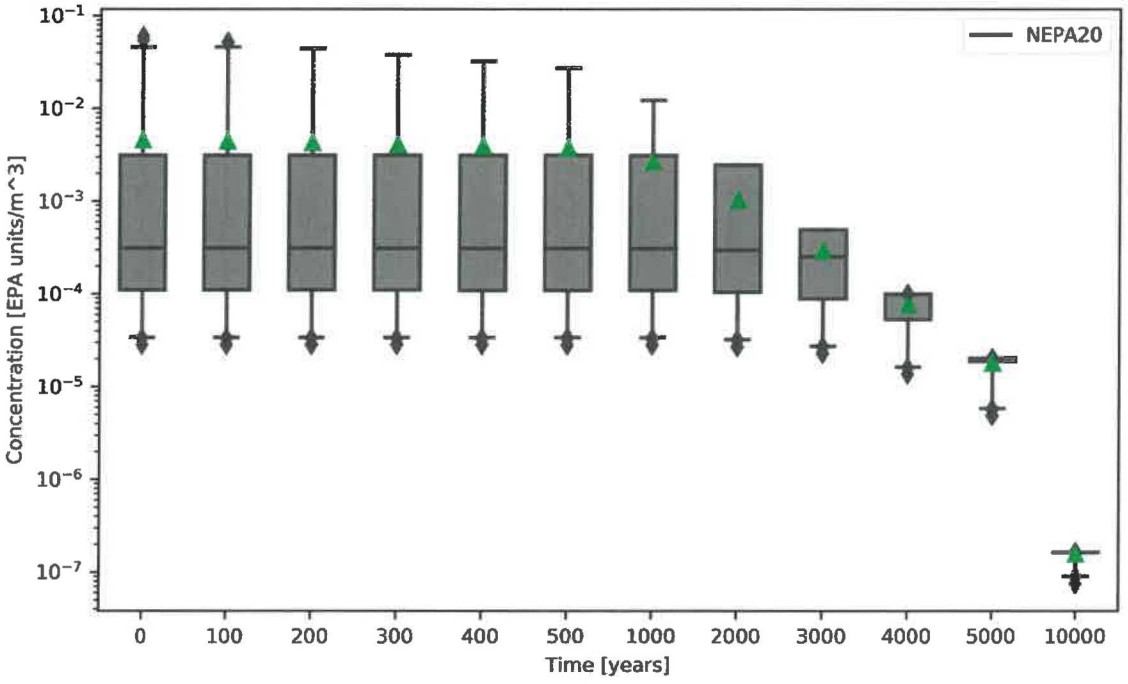

Figure 7-11: AM241L Concentration vs Time, Castile Brine (where the green triangle represents the mean value)

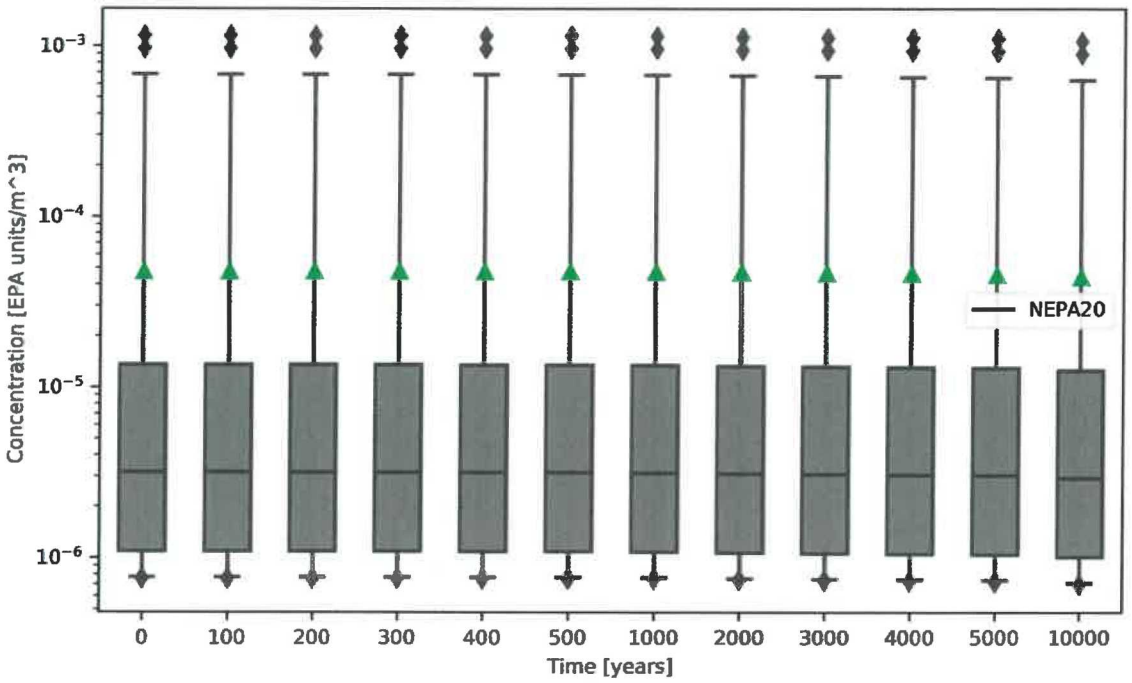

Figure 7-12: PU239L Concentration vs Time, Castile Brine (where the green triangle represents the mean value)

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8 Intrusion Time Determination: Convolution of BRAGFLO_DBR and PANEL Results

This section describes the convolution of BRAGFLO DBR volumes (Section 5) and PANEL radionuclide mobilization concentrations (Section 7) into releases to be used as input for the drilling crew pathway dose calculation (Section 13). In these calculations, the intrusion times used for dose calculations in the drilling crew pathway are determined by the time that maximizes releases. This convolution is typically calculated in the CCDFGF code at the time of intrusion, but only in EPA units; because the dose calculations (Section 13) require input in curies, the convolution is performed outside of the CCDFGF code for the NEPA20 analysis and documented in this section.

8.1 Introduction

The BRAGFLO_DBR code (Section 5) calculates the volume of brine released in a wellbore blowout as well as the volume of brine in the intruded waste panel at the time of intrusion. The convolution calculation described in this section uses only the Lower intrusion location from the BRAGFLO DBR results, as this maximizes the release compared to other potential intrusion locations.

The PANEL code (Section 7) calculates the mobilized radionuclides concentrations in different brine volumes. Using the BRAGFLO_DBR and PANEL outputs, the radionuclide concentration from a wellbore blowout is linearly interpolated across brine volumes of the PANEL concentration to the output brine volume in the panel from BRAGFLO DBR. The interpolated concentration is then multiplied by the volume of brine released to get the total radionuclide release. The largest release volumes come from the S2-DBR and S3-DBR scenarios, which model an intrusion subsequent to an earlier E1 (i.e., Castile brine) intrusion.

The concentrations for different brine volumes from the PANEL code are linearly interpolated to the panel brine volumes from BRAGFLO DBR using Equation (8-1):

$$RC_{r,t} = C_{r,i,t} + \left(PV_t - BV_{i,t}\right)\frac{C_{r,i+1,t} - C_{r,i,t}}{BV_{i+1,t} - BV_{i,t}} \quad (8\text{-}1)$$

where:

$r = radionuclide$
$t = time\ point$
$i = panel\ brine\ volume\ index$
$RC = release\ concentration(Ci/m^3)$
$PV_t = intruded\ panel\ brine\ volume(m^3)$
$C_{r,i,r} = PANEL - calculated\ concentration$
$BV_{i,t} = panel\ brine\ volume$

with the panel brine volume index *i* selected such that:

$$BV_{i,t} < PV_t < BV_{i+1,t}$$

for all radionuclides of interest at all DBR intrusion times.

The interpolated concentrations are then multiplied by the released brine volume for each vector.

8.2 Results

Mean and median radionuclide releases are shown in Figure 8-1 for the S2-DBR scenario. The mean is greater than the median, so the time point that maximizes the mean releases is used for the dose calculation. For S2-DBR, the maximum release comes from an intrusion at 750 years.

Results for S3-DBR are shown in Figure 8-2. For S3-DBR, the first intrusion time at 1200 years produces the maximum mean release. Table 8-1 shows the calculated direct brine releases for the drilling crew pathway dose calculation (Section 13). Mean and median releases across 300 vectors are tabulated for scenarios S2-DBR and S3-DBR.

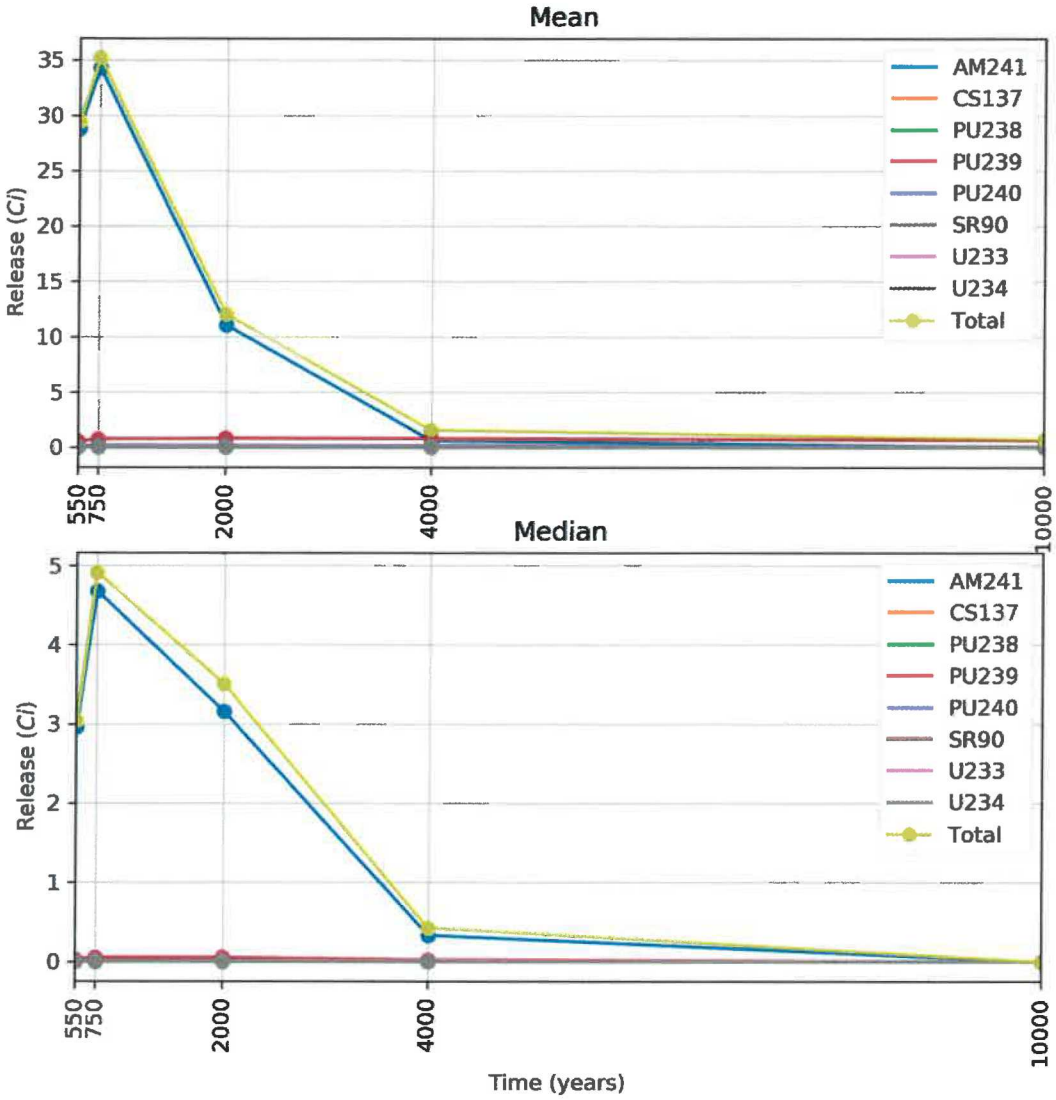

Figure 8-1: Mean and Median Radionuclide Release from Scenario S2-DBR

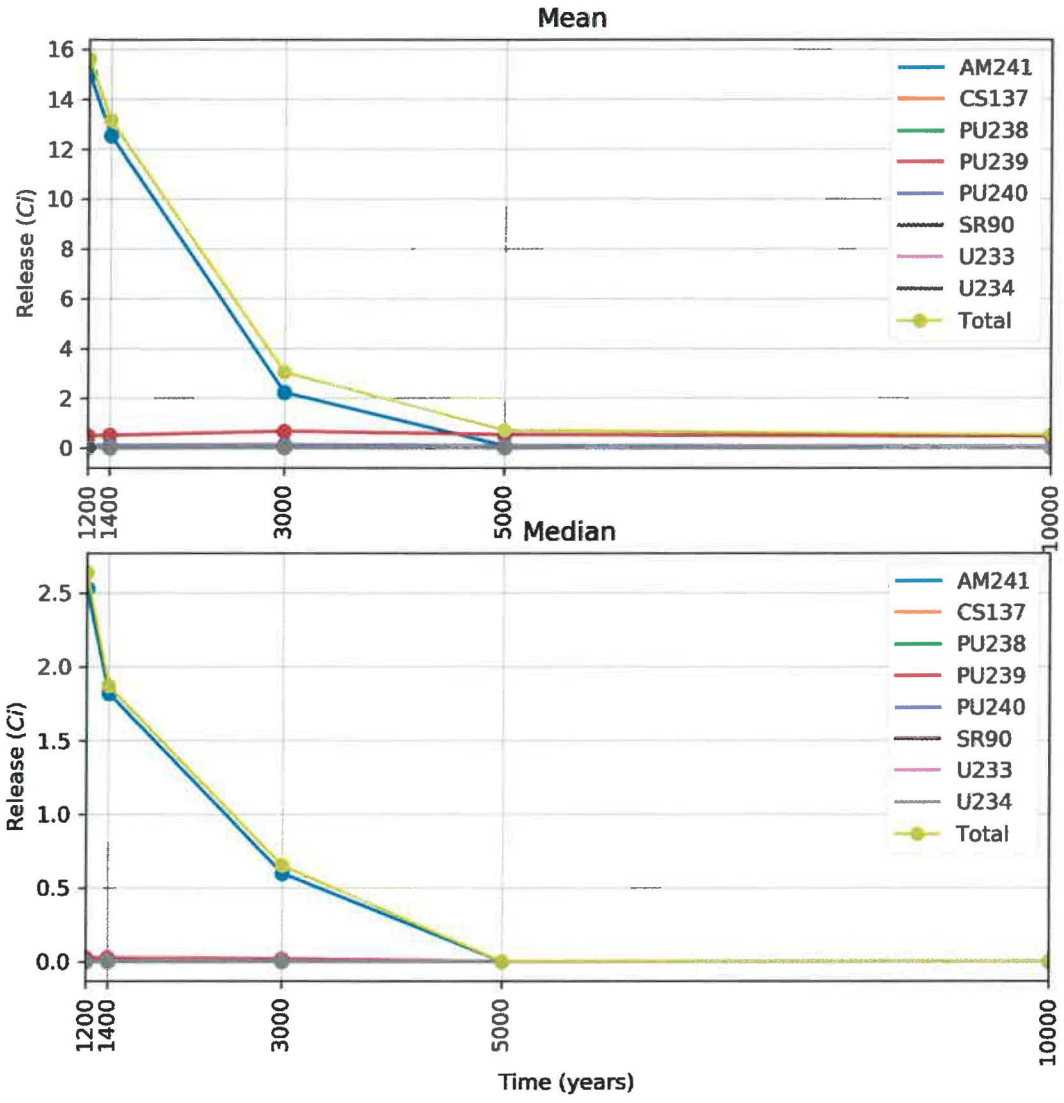

Figure 8-2: Mean and Median Radionuclide Releases for Scenario S3-DBR

Table 8-1: Direct Brine Releases by Radionuclide (in Ci) for Drilling Crew Dose Calculation

Statistic	Scenario	Intrusion Time	Am-241	Cs-137	Pu-238	Pu-239	Pu-240	Sr-90	U-233	U-234	Total
	#	Years	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Mean	S2-DBR	750	3.43E+01	3.45E-07	3.81E-04	7.35E-01	1.73E-01	1.61E-07	1.90E-03	2.37E-02	3.52E+01
Median	S2-DBR	750	4.68E+00	3.50E-07	2.62E-05	5.05E-02	1.19E-02	1.64E-07	1.05E-05	1.32E-04	4.91E+00
Mean	S3-DBR	1200	1.50E+01	6.99E-12	7.24E-06	4.82E-01	1.10E-01	2.38E-12	1.09E-03	1.35E-02	1.56E+01
Median	S3-DBR	1200	2.53E+00	5.92E-12	3.45E-07	2.30E-02	5.23E-03	2.02E-12	7.45E-06	9.23E-05	2.64E+00

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9 Salado Transport: NUTS and PANEL Calculations

This section discusses the calculated long-term actinide discharges from the repository (i.e., the Salado formation) *to the Culebra* member of the Rustler formation. The cumulative radionuclide discharge vs. time results are typically used by CCDFGF (but with the mineral-, intrinsic-, and microbial-colloid-bound actinides filtered out) to calculate *from the Culebra* releases to the land withdrawal boundary (LWB) in EPA units. For the NEPA20 analysis, these transport results (in Ci) are also used in dose calculations (Section 13). For this analysis, Salado transport and Culebra transport results (Section 10) are combined as described in Section 11 to provide the input needed for dose calculations.

9.1 Introduction

The NUTS code performs decay and mass transport calculations in the Salado formation using only the five lumped radionuclides (the inventory lumping used as input to NUTS is discussed in Kicker (2020)). This contrasts with PANEL, which performs the decay and mass balance calculations on the full set of 30 individual radionuclides (and lumps and reports the lumped values at each timestep). NUTS models three decay chains (Table 9-1), based on the assumption that the lumped isotopes assume the properties of the named isotope.

Table 9-1: Decay Chains Modeled in NUTS Code

AM241L	→				
PU238L	→	U234L	→	TH230L	→
PU239L	→				

*The last radioisotope in a chain is not tracked in NUTS.

NUTS uses the same two-dimensional grid as BRAGFLO and relies on BRAGFLO results for the brine flux (i.e., volumetric flow rate) fields and other fluid and rock properties from scenarios S1-BF through S5-BF (Section 4). It models contaminant advection in the aqueous phase, dissolution and precipitation, and radioactive decay. It does not model diffusion, dispersion, adsorption, or gas-phase transport. Cumulative discharges are tabulated at the intersections of: 1) the borehole and the Culebra formation; and 2) the Marker beds and Land Withdrawal Boundary (LWB).

The PANEL code is used for transport calculations for the S6-BF scenario (the E1E2 intrusion case). This code tabulates radionuclide advection at the borehole and marker bed 138 intersection from brine discharge volume calculated by BRAGFLO.

9.2 Results

Figure 9-1 shows the cumulative (over 10,000 years) brine discharge *to the Culebra* (as calculated by BRAGFLO), and Figure 9-2 shows the cumulative total radionuclide discharges *to the Culebra* (as calculated by NUTS and PANEL), for each scenario (Table 6-2) over 300 vectors. Scenarios S1-BF through S5-BF consider the discharge due to a single intrusion, while scenario S6-BF considers the discharge from a sequence of two intrusions (Table 4-1). Results are not shown for the undisturbed scenario S1-BF, because no discharge to the Culebra is greater than 10^{-8} EPA units. In other scenarios, the mean discharges are heavily skewed by a few vectors, especially for scenarios S4-BF and S5-BF, in which the E2 borehole intrusions do not penetrate the pressurized

Castile brine reservoir. In the E2 intrusion scenarios, few realizations contain both sufficient brine releases and sufficient and sustained pressure gradients to result in significant discharges up the borehole and to the Culebra.

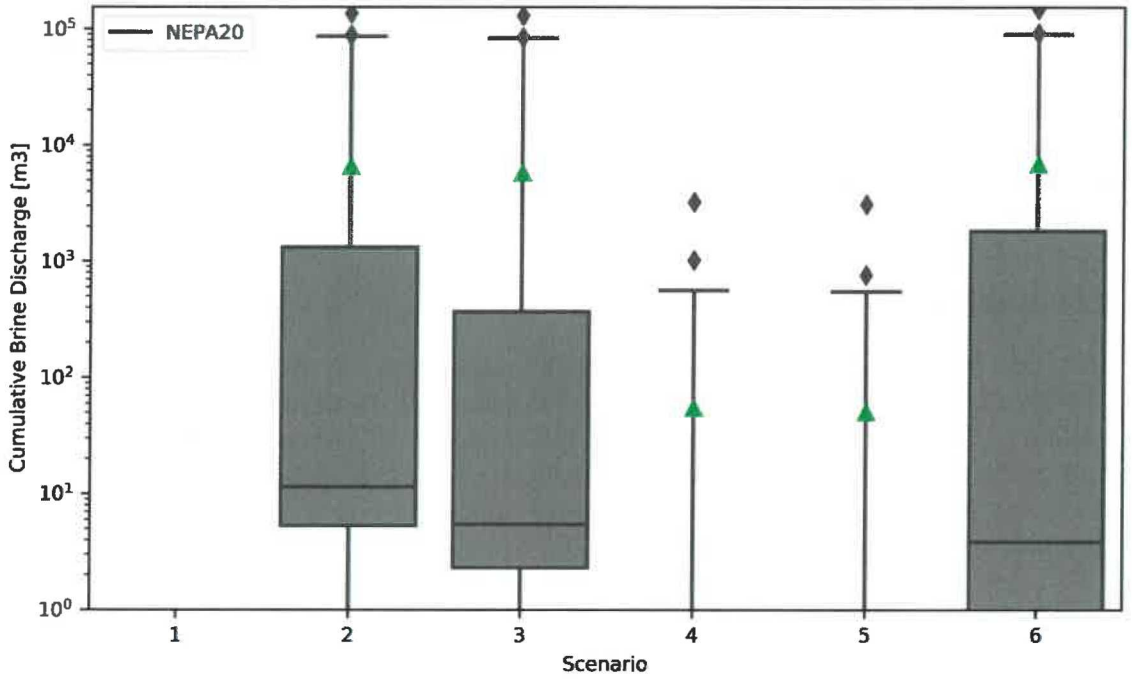


Figure 9-1: Cumulative Brine Volume Discharge to the Culebra from Scenarios S1-BF through S6-BF through 10,000 Years (where the green triangle represents the mean value)

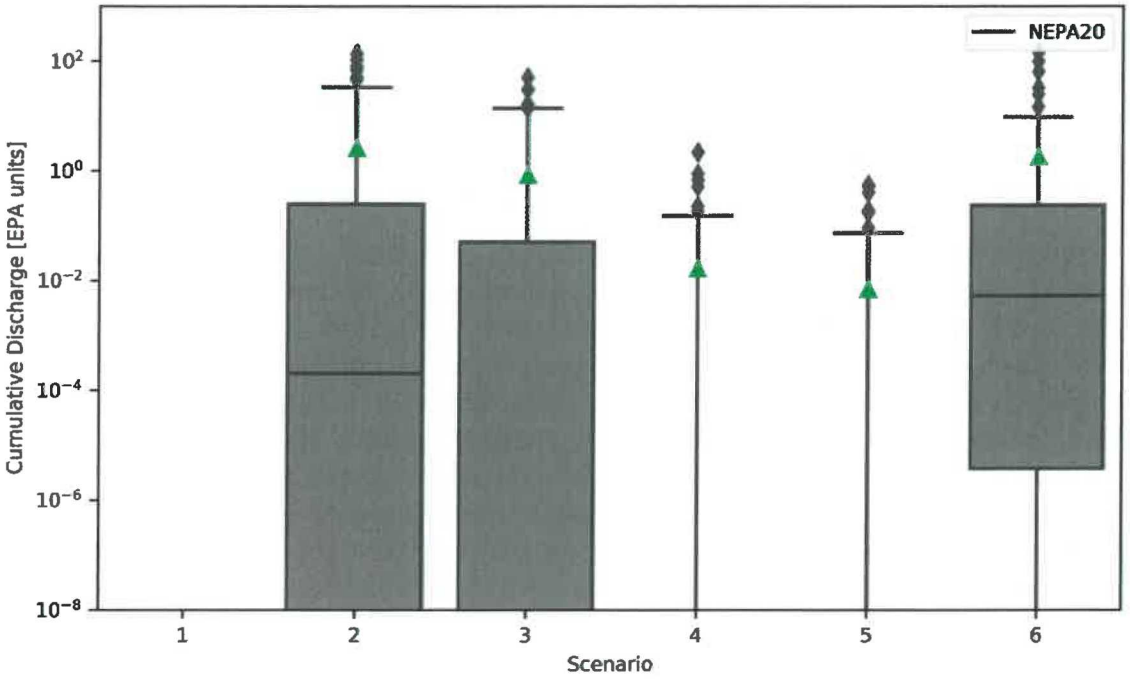


Figure 9-2: Cumulative Radionuclide Discharge to the Culebra in EPA Units for Scenarios S1-BF through S6-BF through 10,000 Years (where the green triangle represents the mean value)

Calculated radionuclide discharges to the Culebra depend on brine discharges and actinide concentrations. High consequence brine discharges are not directly correlated with high actinide concentrations because the two process models are independently parameterized. Therefore, an instance of a relatively high brine discharge may not result in a high radionuclide discharge and, similarly, an instance of a relatively high actinide concentration may not result in a high radionuclide discharge.

The EPA unit concentrations of total lumped radionuclides in Castile brine in Figure 7-10 illustrate the higher mobility of total lumped radionuclides at earlier times than later. In the NEPA20 analysis, the cumulative radionuclide discharges at 10,000 years follow a similar trend in that the earlier the borehole intrusion occurs, the more the cumulative radionuclides are discharged. This can be evidenced by comparing the cumulative discharges at 10,000 years with the cumulative discharge from intrusions at other times listed in Table 9-2..

Table 9-2: Intrusion Times by NUTS (S2-BF through S5-BF) and PANEL (S6-BF)

BRAGFLO Scenarios	Previous Intrusion Type	Subsequent Intrusion Times (year) by NUTS and PANEL
S2-BF	E1 intrusion	100, 350,
S3-BF		1000, 3000, 5000, 7000, 9000
S4-BF	E2 intrusion	100, 350,
S5-BF		1000, 3000, 5000, 7000, 9000
S6-BF	E1E2 intrusion	100, 350, 1000, 2000, 4000, 6000, 9000

The BRAGFLO runs generate the flow data for 10,000 years with the default intrusion times: E1 intrusion at 350 years for S2-BF, E1 intrusion at 1000 years for S3-BF, E2 intrusion at 350 years

for S4-BF, E2 intrusion at 1000 years for S5-BF, and E1 intrusion at 2000 years for S6-BF (Table 4-1). The flow time shift model in the NUTS and PANEL codes utilizes the flow data at default intrusion time to calculate the flow data at other defined intrusion times. The NUTS and PANEL codes use flow data at any (default or defined) intrusion time to calculate cumulative radionuclide discharges to the Culebra at various intrusion times other than the times explicitly simulated in BRAGFLO runs. The time shift model is described in DOE (2019, Appendix PA).

Figure 9-3 shows the cumulative radionuclide discharges at 10,000 years for all intrusion times for each intrusion type. E1 represents total cumulative discharge at 10,000 years when E1 intrusion occurs for S2-BF (100 and 350 years) and S3-BF (1000, 3000, 5000, 7000 and 9000 years). E2 represents total cumulative discharge at 10,000 years when E2 intrusion occurs for S4-BF (100 and 350 years) and S5-BF (1000, 3000, 5000, 7000 and 9000 years). E1E2 represents total cumulative discharge at 10,000 years when an E1 intrusion occurs at 100, 350, 1000, 2000, 4000, 6000 and 9000 years (S6-BF). The similar trend of the mean total cumulative discharge of all the lumped radionuclides is shown in Figure 9-3, where the mean total cumulative discharge decreases as the intrusion time increases. The median total cumulative discharges reveal similar trend exept for the E1E2 intrusion cases, which nearly remain constant. The median E2 data in Figure 9-3 are too small to be seen.

The E1 data at the intrusion time of 100 years in Figure 9-3 show the most discharge at 10,000 years. This intrusion time is used as described in Section 11 to calculate radionuclides in groundwater for the rancher pathway dose calculation (Section 13).

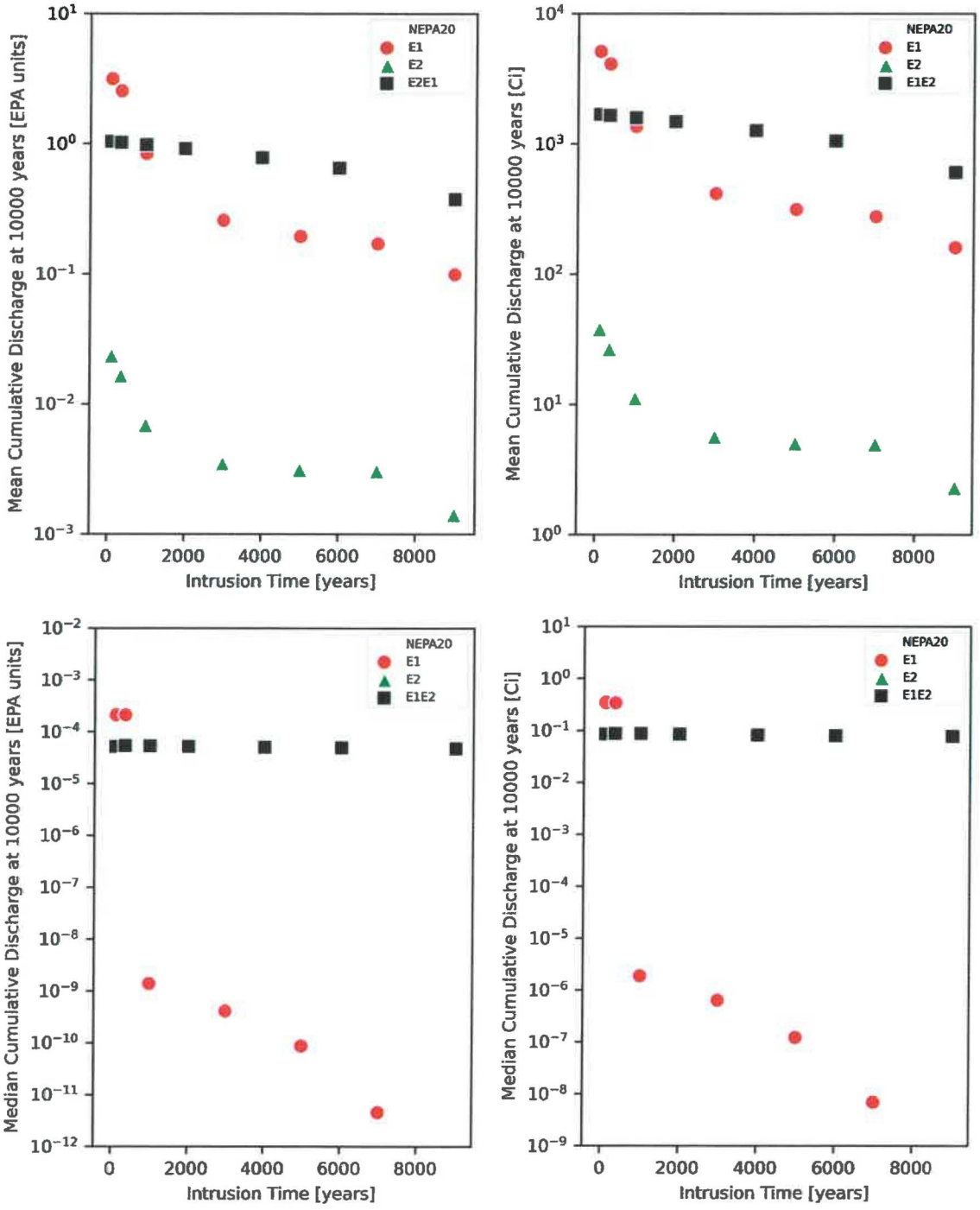
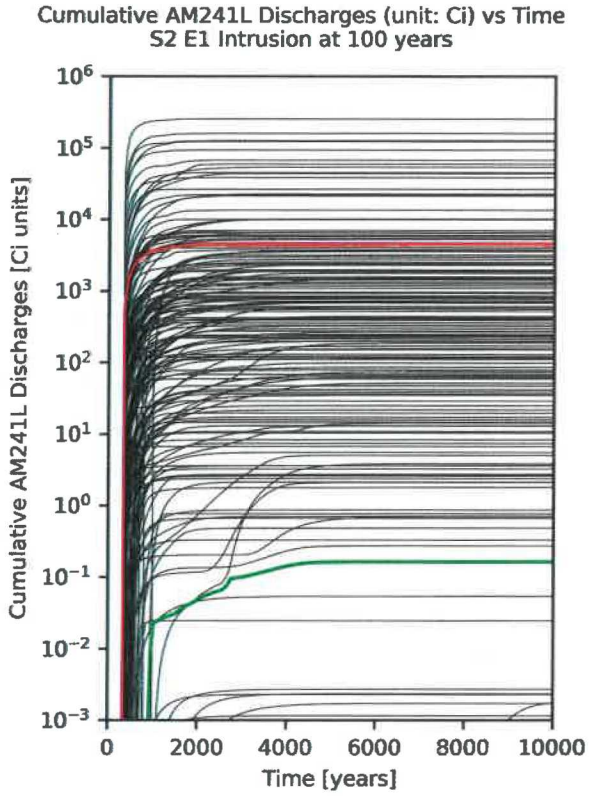


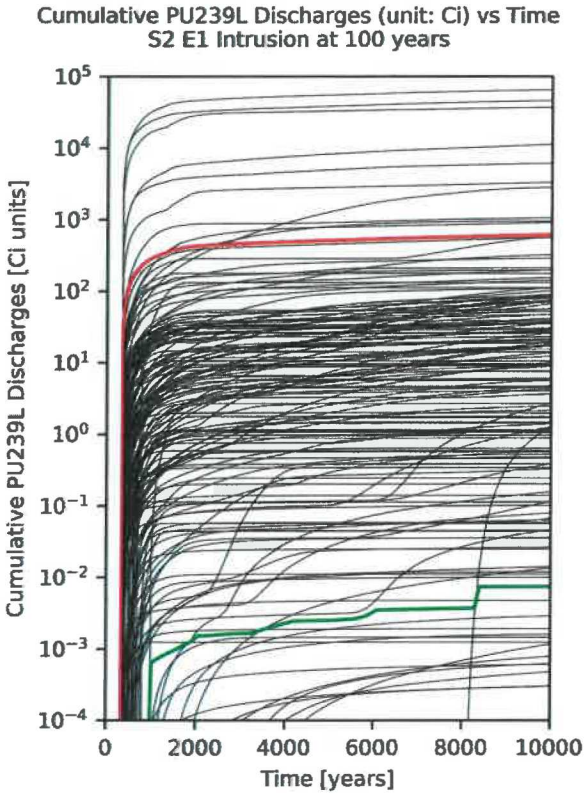
Figure 9-3: Mean and Median Cumulative Discharge of Lumped Radionuclides (Except PU238L) to the Culebra at 10,000 years, in EPA Units (left) and Ci (right)[8]

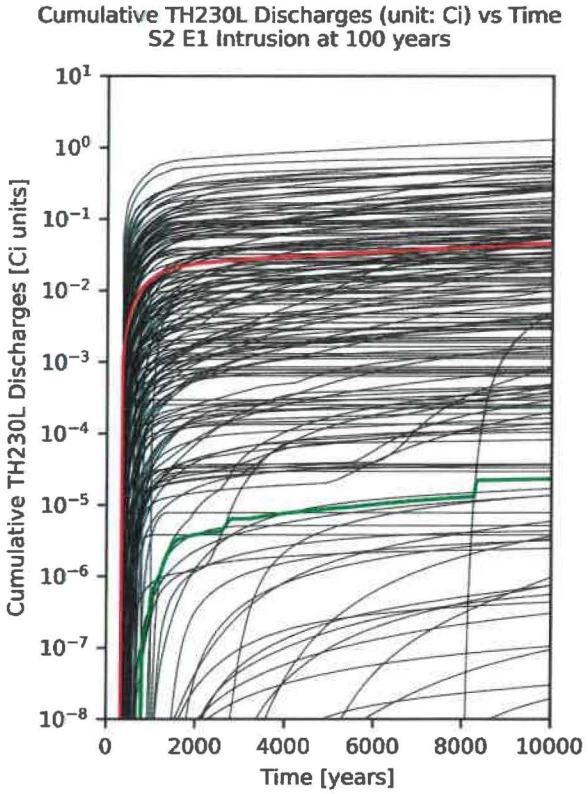
From Figure 9-3 the largest radionuclide release to the Culebra is observed for an E1 intrusion at 100 years; these releases are used for the rancher pathway dose calculation (Section 11). Figure 9-4 shows the cumulative radionuclide and total discharges to the Culebra for a regulatory time period from 100 years to 10,000 years in the scenario S2-BF with the intrusion time at 100 years. Cumulative discharges for 300 vectors are shown. Mean and median values of the cumulative total

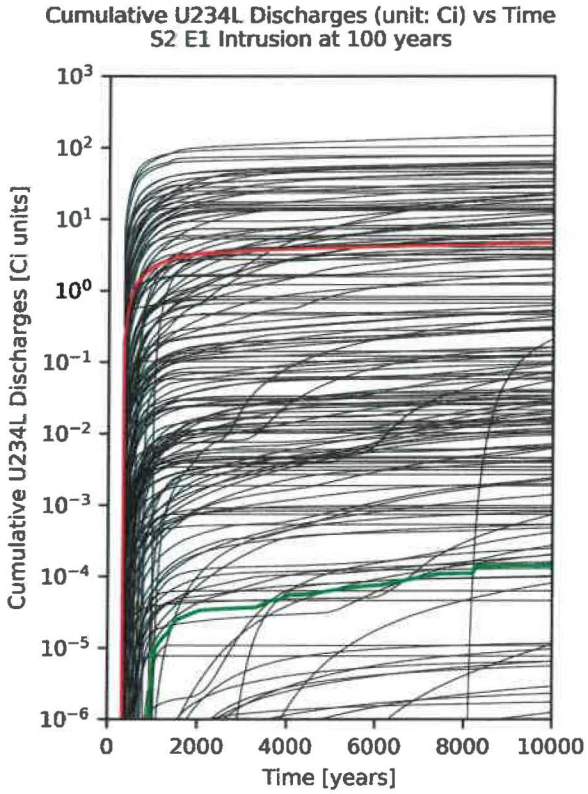
discharge data are represented with a red and green lines, respectively. Limited numbers of vectors govern the mean discharge values, the resulting mean data are higher than the median data.

[8] The very minor contribution of PU238L is not included due to short half-life of 88 years and its insignificant inventory contribution over time as shown in Figure 7-5. E1 intrusions include results from S2-BF and S3-BF scenarios, while E2 intrusions include results from S4-BF and S5-BF scenarios. Intrusion time on the x-axis represents E1 intrusion time for the E1 and E1E2 cases, and E2 intrusion time for the E2 cases.


Cumulative AM241L Discharges (unit: Ci) vs Time
S2 E1 Intrusion at 100 years
Cumulative AM241L Discharges [Ci units]
Time [years]


Cumulative PU239L Discharges (unit: Ci) vs Time
S2 E1 Intrusion at 100 years
Cumulative PU239L Discharges [Ci units]
Time [years]


Cumulative TH230L Discharges (unit: Ci) vs Time
S2 E1 Intrusion at 100 years
Cumulative TH230L Discharges [Ci units]
Time [years]


Cumulative U234L Discharges (unit: Ci) vs Time
S2 E1 Intrusion at 100 years
Cumulative U234L Discharges [Ci units]
Time [years]

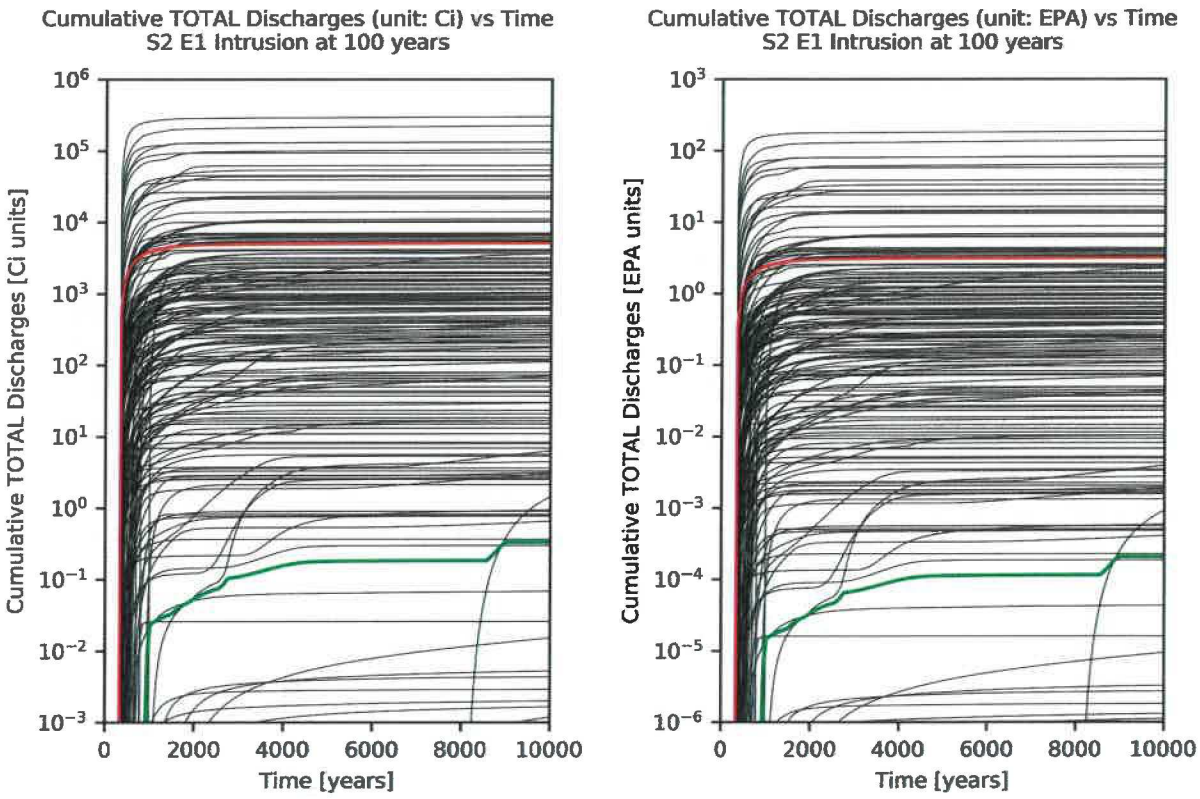


Figure 9-4: Cumulative Discharges to the Culebra in Ci and EPA Units for 10,000 Years, S2-BF, with Default E1 Intrusion Time at 100 Years (where the red line represents mean values and the green line represents median values)

10 Culebra Transport: MODFLOW and SECOTP2D Calculations

This section summarizes the calculations to evaluate the flow and transport in the Culebra to the LWB. The work reported herein is a re-analysis of the transport results described in the PABC-2009 Culebra Flow and Transport Analysis Report (Kuhlman 2010) for use with the NEPA20 rancher pathway dose calculations (Section 13). The calculation approach is briefly summarized below, but for a more comprehensive description of the calculations and results, refer to Kuhlman (2010).

10.1 Introduction

The Culebra Dolomite Member of the Rustler Formation is located stratigraphically above the Salado Formation and contains the most hydraulically transmissive units above the repository. Consequently, the Culebra is the most likely pathway for subsurface transport of radionuclides from the WIPP panels to the accessible environment outside the LWB.

The key steps for estimating radionuclide transport through the Culebra include:

1. Construction of geostatistical realizations of Culebra hydraulic transmissivity (T), anisotropy, storativity, and recharge fields (collectively referred to as "T-fields")
2. Calibration of the T-fields to observed heads
3. Modification of the T-fields to account for potential subsidence due to potash mining beneath the Culebra
4. Calculation of steady-state flow-fields for each mining-modified T-field using MODFLOW
5. Calculation of transport through the Culebra for each flow-field using SECOTP2D

The construction of base geostatistical realizations of Culebra T-fields (step 1) is described in AP-114 Task 5 (Hart et al., 2008), and the calibration of these T-fields (step 2) is described in AP-114 Task 7 (Hart et al., 2009). The mining-modified T-fields (step 3) and radionuclide transport calculations (step 4) are described in the Culebra Flow and Transport Analysis Report (Kuhlman 2010).

For each transport simulation, 1.00 kg of each radionuclide is released at a single point above the center of the repository. The simulations are run for 10,000 years and the cumulative mass fraction crossing the LWB is tabulated in 50-year intervals.

10.2 Results

SECOTP2D results were aggregated from the SUMMARIZE output step[9] of the Culebra Transport workflow (Kuhlman 2010)[10]. Reported mass breakthrough values that are negative or less than 1.00E-99 were set to zero in calculating the reported statistics.

Time-series of the cumulative mass fraction breakthrough at the LWB were calculated by isotope for each breakthrough curve for all replicates and vectors (300 total) in the full mining scenario (Figure 10-1 through Figure 10-5). Many vectors have essentially zero breakthrough at 10,000 years. Results include the four radionuclides (^{241}Am, ^{234}U, ^{230}Th, and ^{239}Pu) released in the Culebra. Transport of the ^{230}Th daughter product of ^{234}U decay is calculated and tracked as a separate species. In the following figures, ^{230}Th refers to the ^{234}U daughter product and ^{230}ThA refers to ^{230}Th released into the Culebra.

[9] Statistics and figures were generated with Python version 3.7, an open source programming language.
[10] SECOTP2D was not re-run for the NEPA20 analysis, but the results used in the CRA19 analysis were used (Zeitler et al. 2019). No inputs would have been different for the NEPA20 analysis and thus there would be no difference in output if it had been re-run.

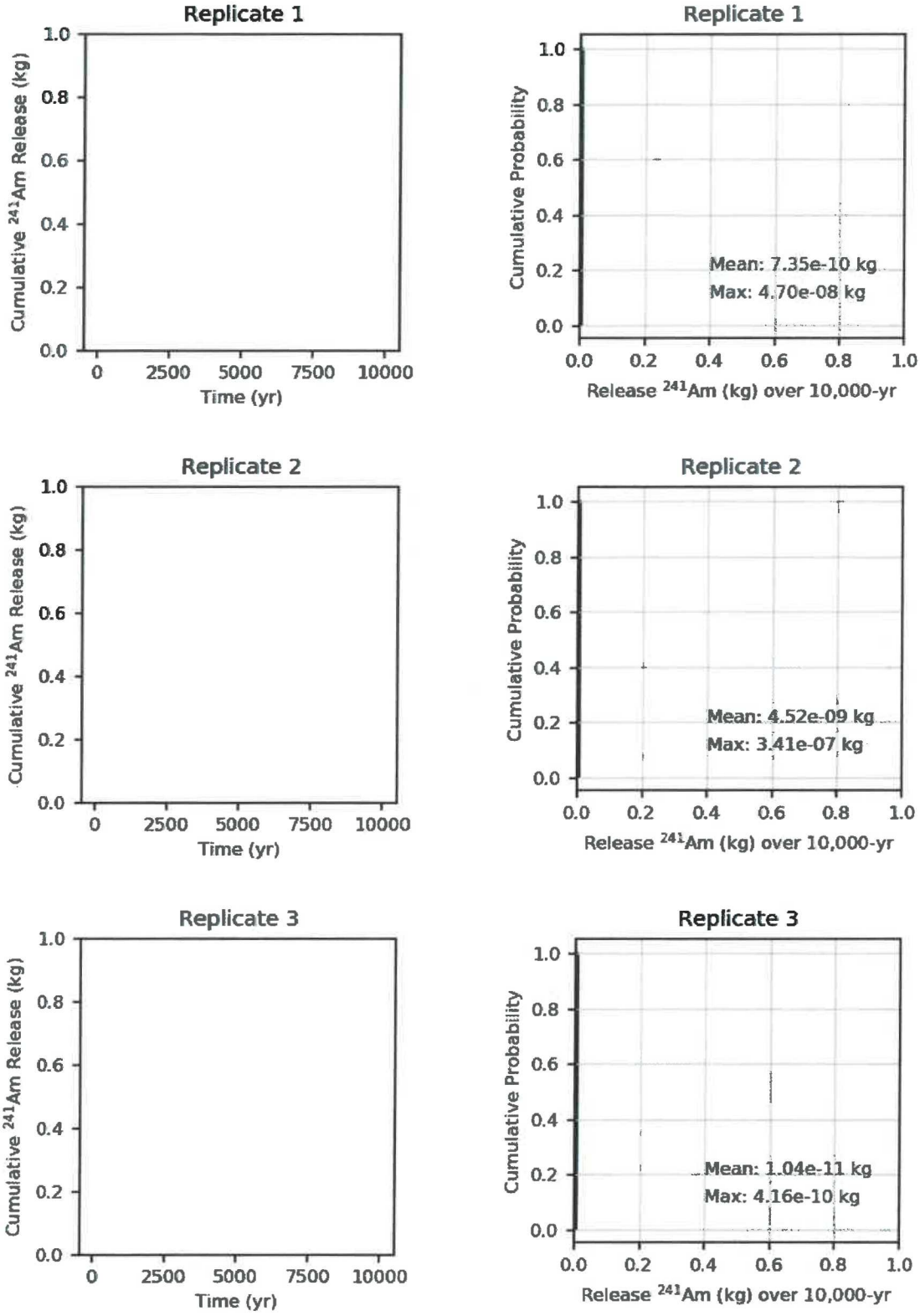


Figure 10-1: Cumulative Breakthrough at the LWB of ^{241}Am

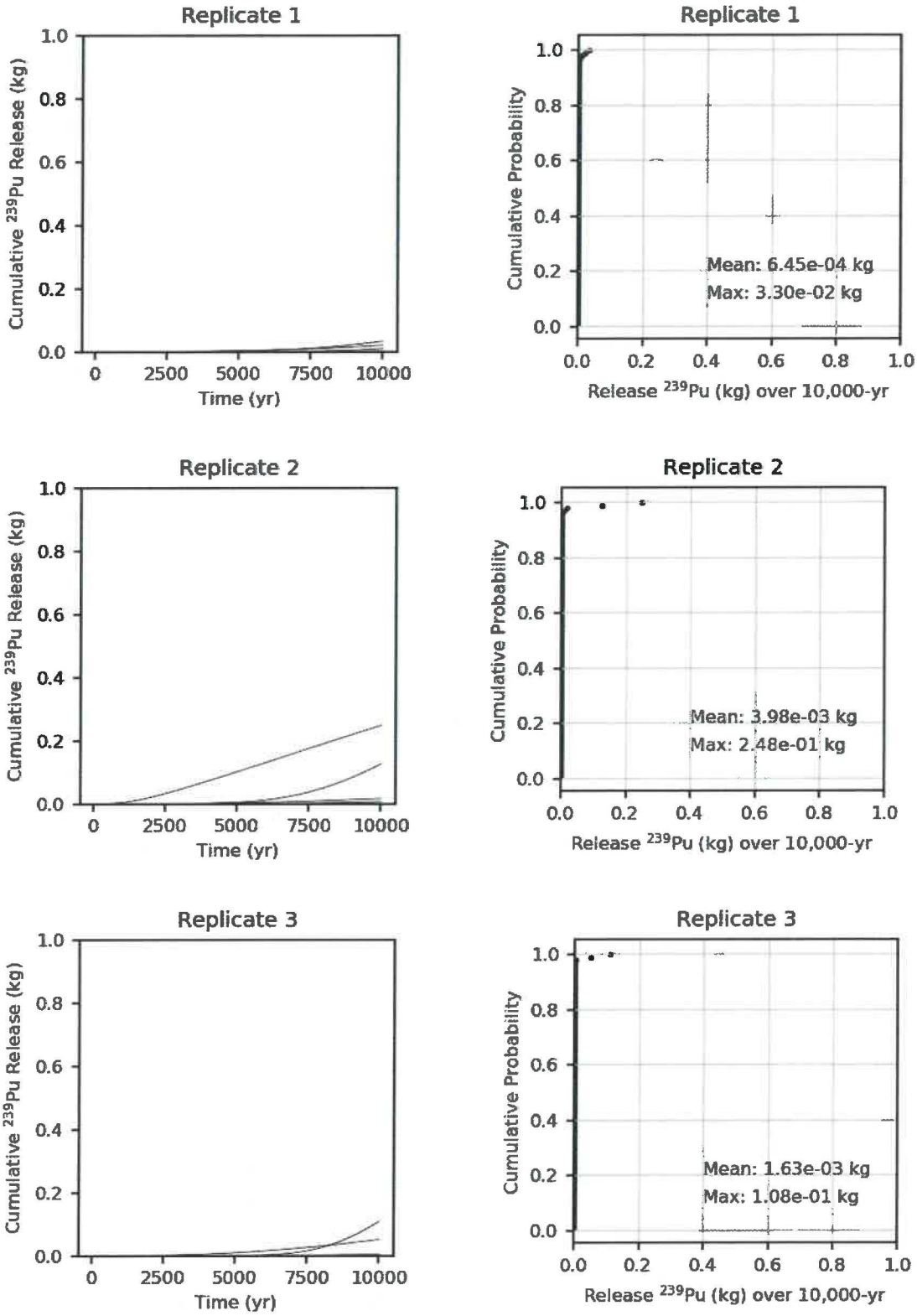


Figure 10-2: Cumulative Breakthrough at the LWB of ^{239}Pu

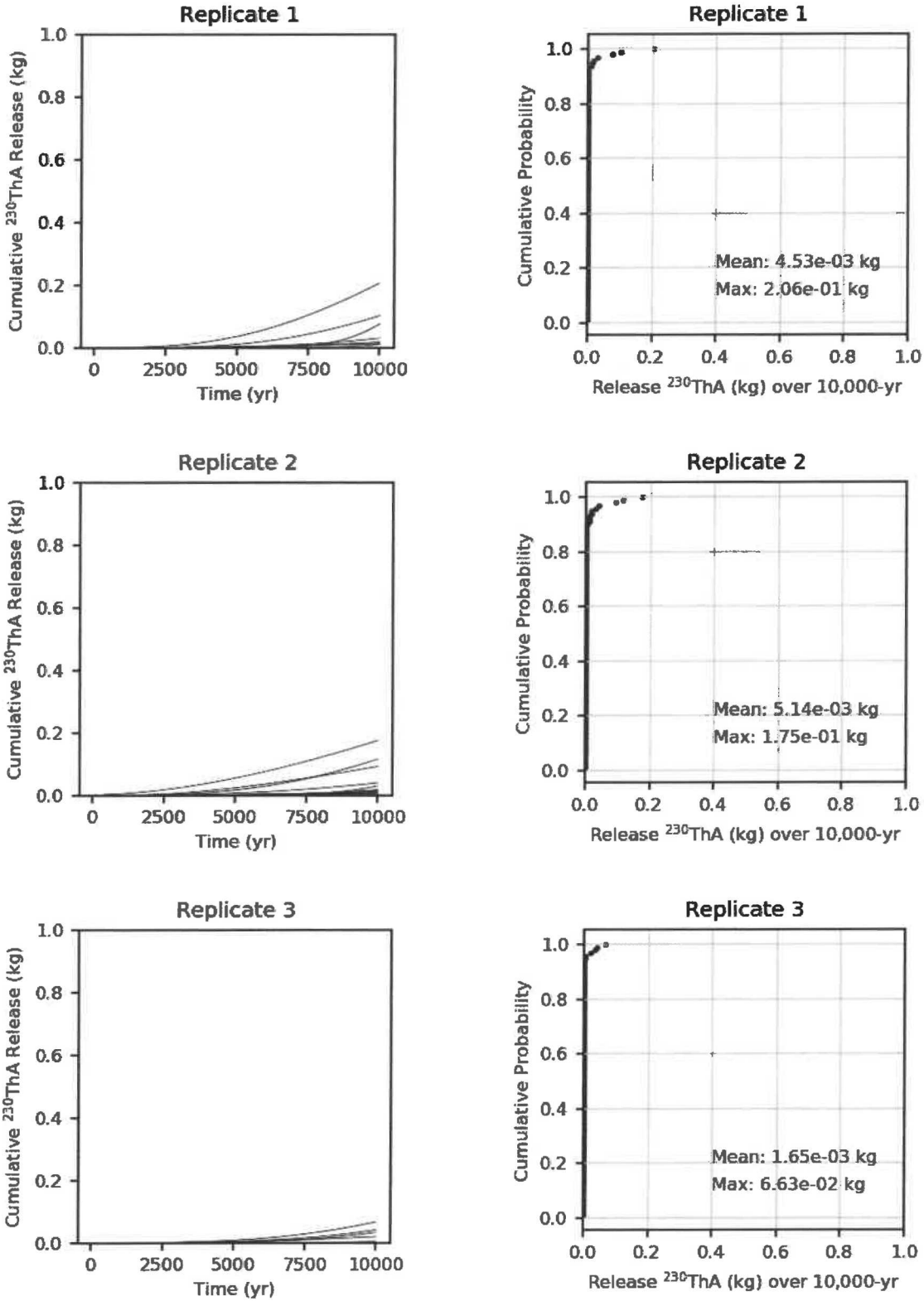


Figure 10-3: Cumulative Breakthrough at the LWB of ^{230}ThA

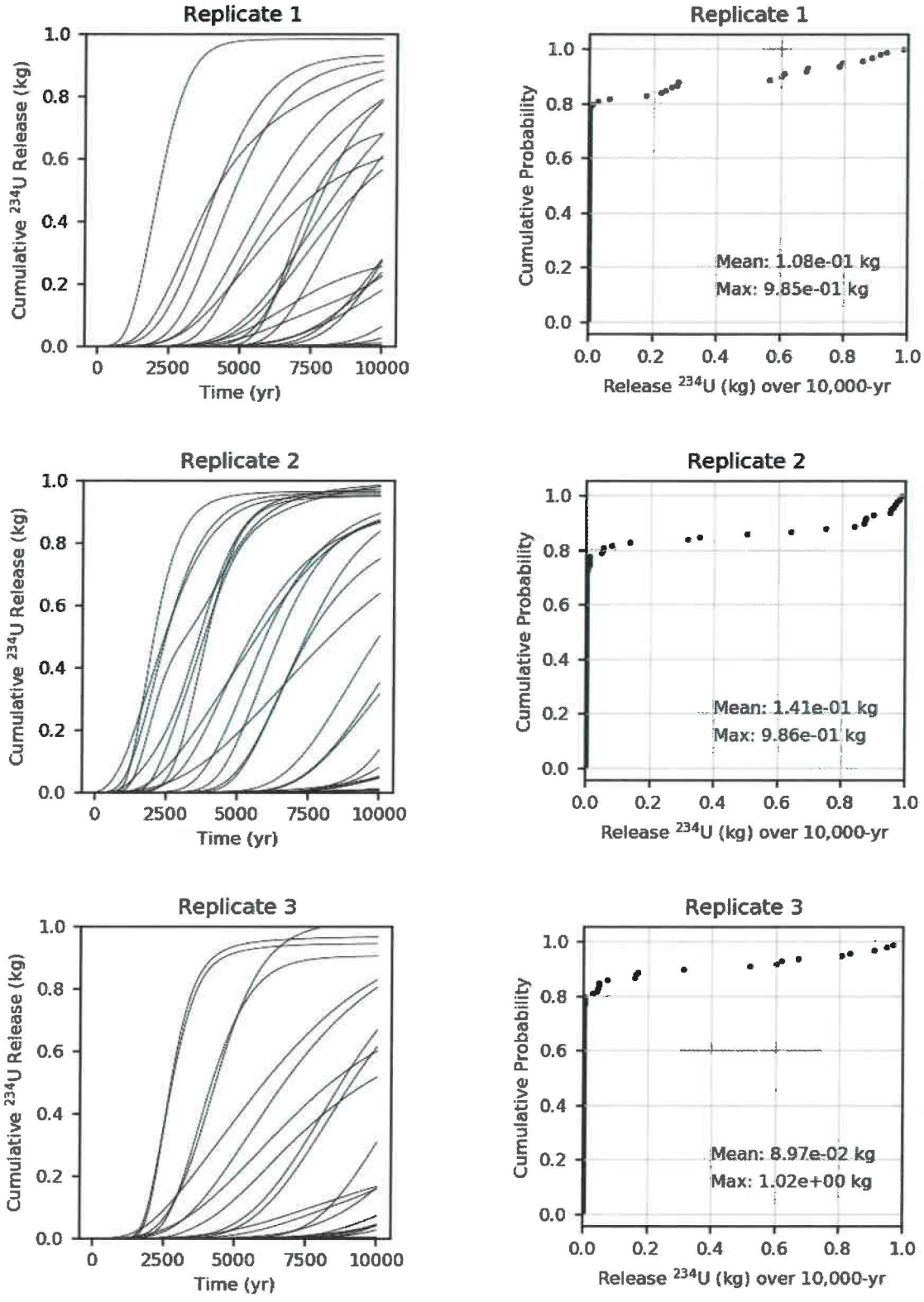


Figure 10-4: Cumulative Breakthrough at the LWB of ^{234}U

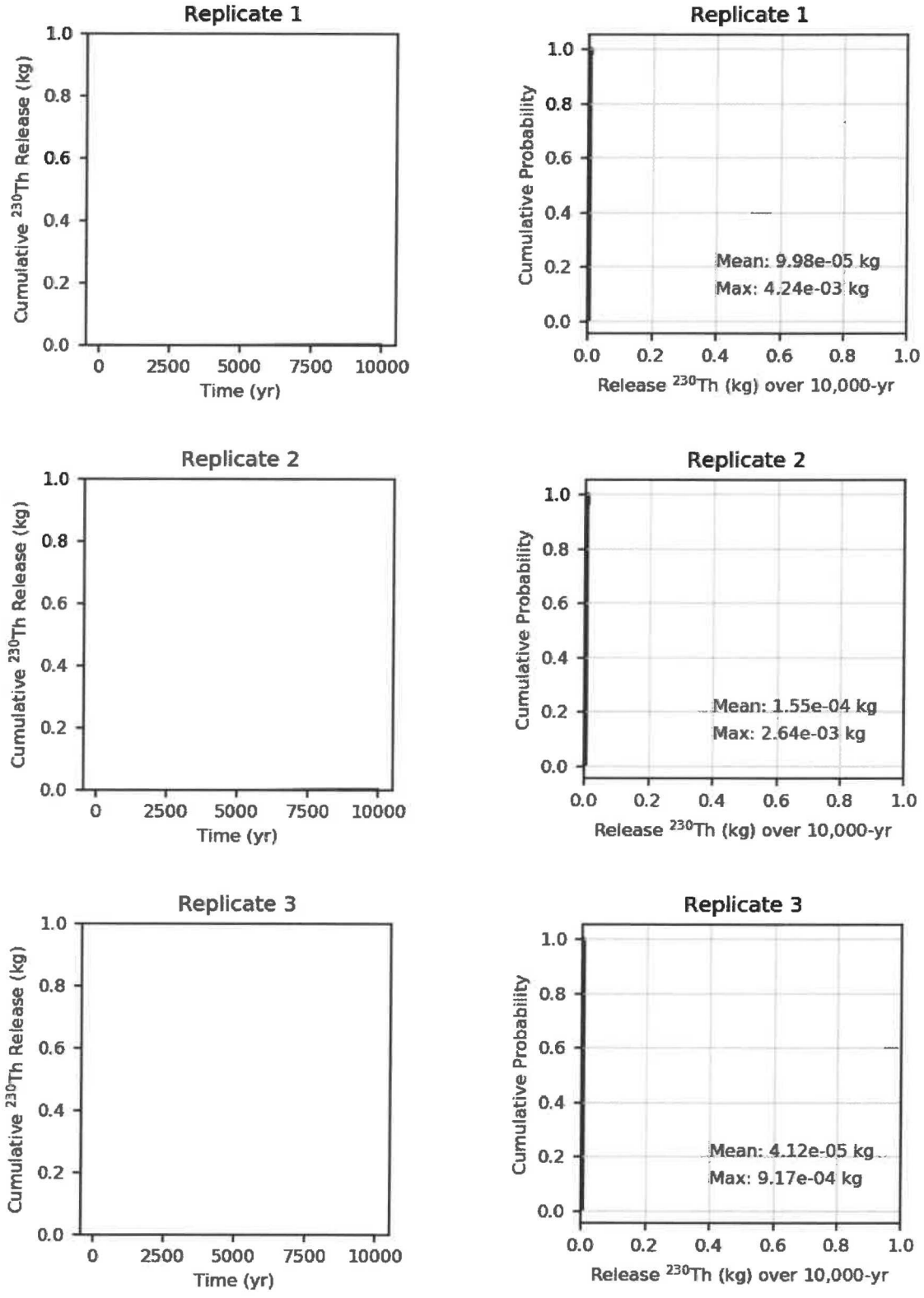


Figure 10-5: Cumulative Breakthrough at the LWB of ^{230}Th Full Mining Cumulative Breakthrough at the LWB

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11 Intrusion Time Determination: Convolutions of NUTS and SECOTP2D Results

This section describes the calculation of radionuclide mass dissolved in groundwater at the LWB used for the evaluation of dose by the rancher pathway (Section 13). The PA code NUTS calculates radionuclide fluxes from the repository to the Culebra (Section 9) and the PA code SECOTP2D computes fractional releases of radionuclides through the Culebra to the LWB (Section 10). This section describes the convolution of these results to obtain radionuclide fluxes at the LWB. The intrusion time assumed for the rancher pathway is selected to maximize the mean radionuclide flux used in the dose calculations.

11.1 Introduction

NUTS calculates radionuclide transport to the Culebra (Section 9) and SECOTP2D calculates the fraction of radionuclides entering the Culebra that transport to the LWB (Section 10) over period of time. In PA compliance calculations, the code CCDFGF convolves the output of NUTS and SECOTP2D to calculate cumulative releases from the Culebra at 10,000 years for random intrusions (WIPP PA 2010). For the NEPA20 analysis, the convolution of NUTS and SECOTP2D output calculates releases through the Culebra at any point in time following a single intrusion using Equation 11-1 (adapted from Eqn. 27, WIPP PA (2010)):

$$R(\tau; I) = \sum_{t_i=I}^{\tau} (r(t_i) * f(t_i, \tau)) \qquad (11\text{-}1)$$

where:

$R(\tau; I)$ is cumulative release at the LWB of a radionuclide (Ci), including colloidal contributions, at time τ (where $I < \tau \leq 10{,}000$)

$r(t_i)$ is release (Ci) to the Culebra in the time interval [t_i, t_i+50 yr] , including colloidal contributions, from the NUTS output

$f(t_i, \tau)$ is the fraction of the radionuclide released into the Culebra over the time interval [t_i, t_i+50 yr] that reaches the LWB by time τ, from the SECOTP2D output

I is the assumed intrusion time (yr).

Only the full mining scenario results from the SECOTP2D output (Section 10) are considered here, as the travel time through the Culebra is faster in the full mining scenario than in the partial mining scenario. Radionuclide flux to the Culebra is considered for various scenarios from the NUTS output (Section 9).

Microbial, intrinsic, and humic colloids and mineral fragment are included in the radionuclide flux to the Culebra. However, these colloid forms, except humic colloid, are not considered to transport through the Culebra (DOE 2019, Appendix MASS). The fraction of radionuclide mass sorbed to each colloid is quantified by the output of the code PANEL (Section 7.2.2), and the release to the LWB is adjusted using Equation 11-2**Error! Reference source not found.** to remove colloidal contributions:

$$R_{corrected}(\tau; I) = R(\tau; I) * \left(1 - f_{microbial} - f_{intrinsic} - f_{mineral\ fragment}\right) \quad (11\text{-}2)$$

where:

$R_{corrected}$ is cumulative release (Ci) through the Culebra without non-transporting colloidal contributions

R is total release at the LWB (Ci) from Equation 11-1**Error! Reference source not found.**

f_j is fraction of radionuclide mass associated with colloid type j (unitless).

Transport calculations into and through the Culebra are performed with the same isotope lumping scheme as in the PA compliance calculations. The activity ratio of individual isotopes at the end of the regulatory period is used to partition the lumped isotope into its constituent radionuclides.

The annual release rate can be found by differentiating the corrected cumulative releases through the Culebra, found in Equation 11-2:

$$F(\tau; I) = \frac{\partial}{\partial \tau}\left(R_{corrected}(\tau; I)\right) \quad (11\text{-}3)$$

where:

$F(\tau{:}I)$ is the annual release rate at the LWB (Ci/yr)

τ is the point in time of the release after the intrusion $(I < \tau \leq 10{,}000)$

From equation 11-3, the peak annual release rate can be found as the maximum of the annual release rate:

$$F_{max}(I) = \max_{\tau}\{F(\tau; I):\ I < \tau \leq 10{,}000\} \quad (11\text{-}4)$$

Results were processed from selected NUTS, PANEL, and SECOTP2D scenario. NUTS E1 intrusion scenarios were considered (including intrusions at 100 and 350 years based on the S2-BF scenario, and intrusions at 1000, 3000, 5000, 7000 and 9000 years based on the S3-BF scenario) to be consistent with the other intrusion dose pathway calculations and to get good coverage of possible intrusion times. The cumulative discharges of radionuclides to the Culebra, for instance, are shown with a default E1 intrusion time of 100 years in Figure 9-4. Radionuclide solubilities are calculated in the Castile brine for consistency with the NUTS scenarios, which assume intrusions that intersect Castile brine pockets. SECOTP2D full-mining output was selected for conservatism because transport times are faster in the full-mining output than in the partial mining scenario. For simplicity, the calculations are done in Excel.

The PANEL decay mode calculates inventory changes of all individual radionuclides due to decay and ingrowth. At each time step, the activity fraction of an individual radionuclide is calculated by dividing its activity by total activity of its corresponding lumped radionuclide.

Mean and median results from the convolution of the NUTS and SECOTP2D time series were calculated over all three replicates (i.e., 300 vectors) for each intrusion scenario. SECOTP2D does not consider different intrusion times or different LWB accumulation times directly in its

calculations, but rather the convolution accounts for different residence times in the Culebra by selecting a different range of the same SECOTP2D cumulative flux time series output since flow in the Culebra is steady once the mining scenario is specified.

NUTS calculates the time-dependent releases of lumped radionuclides to the Culebra from the time of intrusion until 10,000 years post-closure and SECOTP2D calculates the transport releases through the Culebra to the LWB. Release to the Culebra (NUTS, shown in Figure 9-4 for intrusion times of 100-yrs) is multiplied by the fraction released through the Culebra (SECOTP2D, Figure 10-1 through Figure 10-5) across the specified accumulation time period. The specified accumulation time period is varied between the intrusion time and 10,000 years. The cumulative releases as a function of accumulation time are then differentiated with respect to accumulation time to get an annual release rate. The resulting release rates from the Culebra are screened for peak release rate in order to determine the intrusion time that results in maximum peak release rate from the Culebra for a single intrusion.

The lumped radionuclide release rate to the LWB is then multiplied by the isotope fraction (as determined by PANEL) in order to determine releases for individual isotopes for use in dose calculations (Equation 11-5):

$$F_{max,k}(I) = F_{max}(I) \times a_k(t = \tau_{max})/a_{k,lumped}(t = \tau_{max}) \quad (11\text{-}5)$$

where:

$F_{max,\,k}(I)$ is peak release rate at the LWB (Ci/yr) for isotope k from an intrusion at time I

$F_{max}(I)$ is peak cumulative release (Ci/yr) through the Culebra without colloidal contributions from Equation 11-4

$a_k(t = \tau_{max})$ is the activity of radionuclide k (from PANEL) at the time that maximizes the release rate

$a_{k,lumped}(t = \tau_{max})$ is the activity of the lumped radionuclide containing radionuclide k (from PANEL) at the time that maximizes the release rate

I is intrusion time (yr).

11.2 Results

The PANEL code calculates inventory changes for all individual radionuclides due to decay and ingrowth. At each time step, the lumped fraction of an individual radionuclide is calculated following the method described in Leigh and Trone (2005) considering the full inventory. The resulting fractions of each isotope at 10,000 years is shown for t=0 yrs and t=10,000 yrs in Table 11-1. The peak release time isotopic fractions are found by linearly interpolating between the 0- and 10,000-year fractions to subdivide the lumped releases into releases of individual isotopes for the dose calculations. Colloidal fractions are calculated at the time of closure and do not change with time.

Table 11-1: Isotope Fractions in Lumped NUTS and SECOTP2D Isotopes

Lumped	Individual	Half-Life (Yr) [a]	Inventory at 0 yrs (Ci) [b]	Isotope Fraction @ 0 yrs [c]	Total Ci at 10,000 yrs [d]	Isotope Fraction @ 10,000 yrs [e]
AM241L	AM241	1.36E+10	3.22E+06	0.969	8.59E+00	0.971
	PU241	4.54E+08	3.06E+06	0.031	7.81E+00	0.029
PU239L	PU239	7.59E+11	8.77E+06	0.799	6.58E+06	0.896
	PU240	2.06E+11	2.19E+06	0.200	7.60E+05	0.104
	PU242	1.22E+13	5.12E+02	0.001	5.03E+02	0.001
PU238L	PU238	2.77E+09	1.99E+06	1.000	9.81E-29	1.000
U234L	U234	7.72E+12	1.11E+03	0.884	1.77E+03	0.913
	U233	5.00E+12	1.45E+02	0.116	1.69E+02	0.087
TH230L	TH230	2.43E+12	7.54E+00	0.590	1.61E+02	0.619
	TH229	2.32E+11	5.24E+00	0.410	9.86E+01	0.381

a: PANEL; HALFLIFE
b: PANEL: INVCHD + INVRHD at t=0 yrs, $a_k(t_l)$ in Equation 11-5
c: PANEL; $a_k(t_l)/a_{k,lumped}(t_l)$ in Equation 11-5 at t=0 yrs
d: PANEL; INVCHD + INVRHD at t=10,000 yrs, $a_k(t_l)$ in Equation 11-5
e: PANEL; $a_k(t_l)/a_{k,lumped}(t_l)$ in Equation 11-5 at t=10,000 yrs

The mean and median peak release rate values across the 300 vectors for the resulting individual isotope releases F_{max} (in Ci/yr) at the LWB are shown in Figure 11-1 through Figure 11-2 for all considered intrusion times. An intrusion at 100 years is observed to produce the largest mean and median releases, so an intrusion at 100 years is assumed for dose calculations. In general, earlier time intrusions were found to lead to greater peak release rate at the LWB as more time is available for transport, despite inventory reduction due to decay. Mean releases are found to be higher than the median releases in all cases.

Table 11-2 summarizes the cumulative activity by radionuclide from the 100-year intrusion calculations that are used in dose calculations (Section 13). The cumulative releases include all radionuclide mass transported across the LWB over the 10,000-year regulatory period under the assumptions considered.

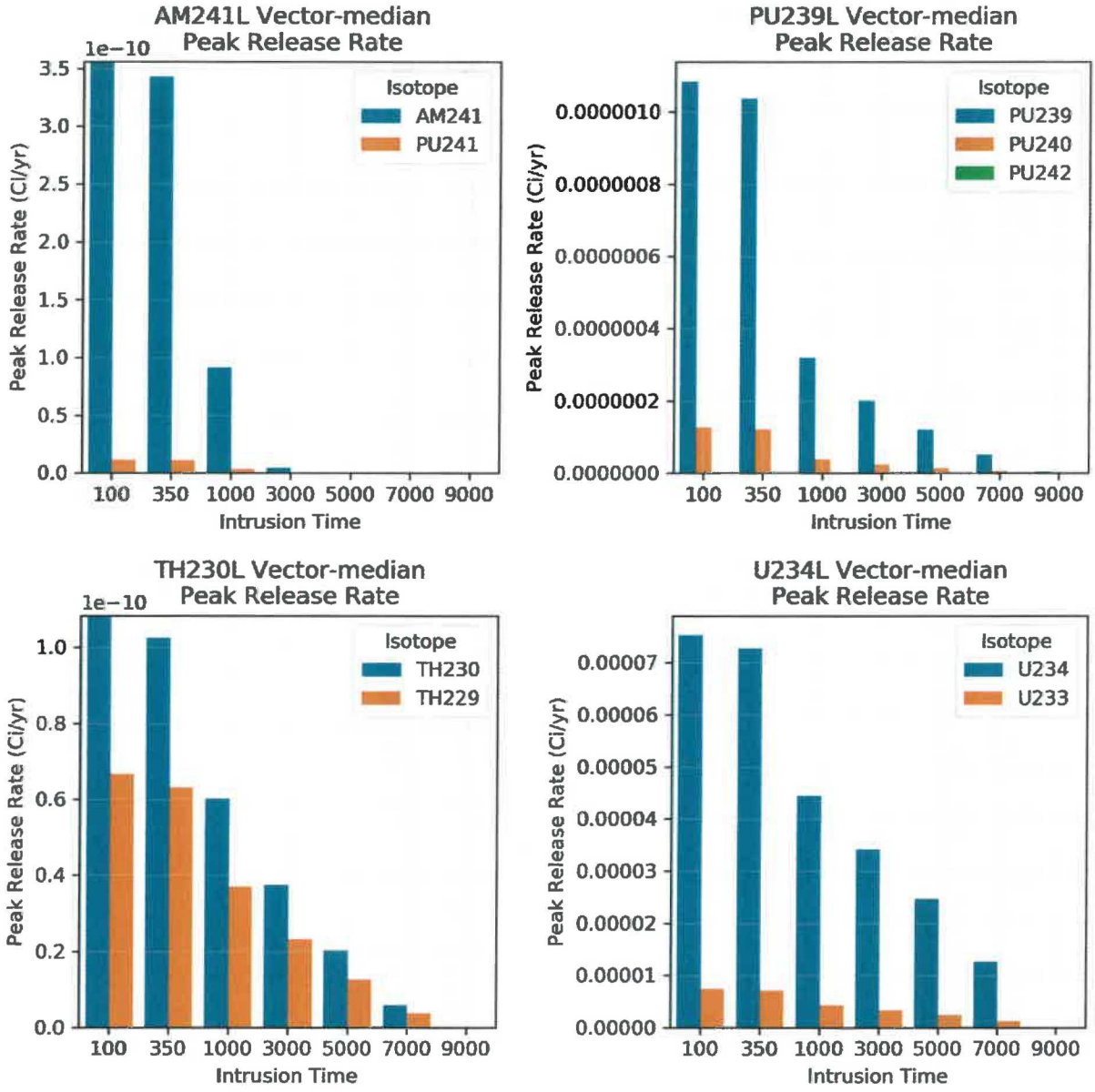

Figure 11-1: Mean Peak Release Rates to the LWB

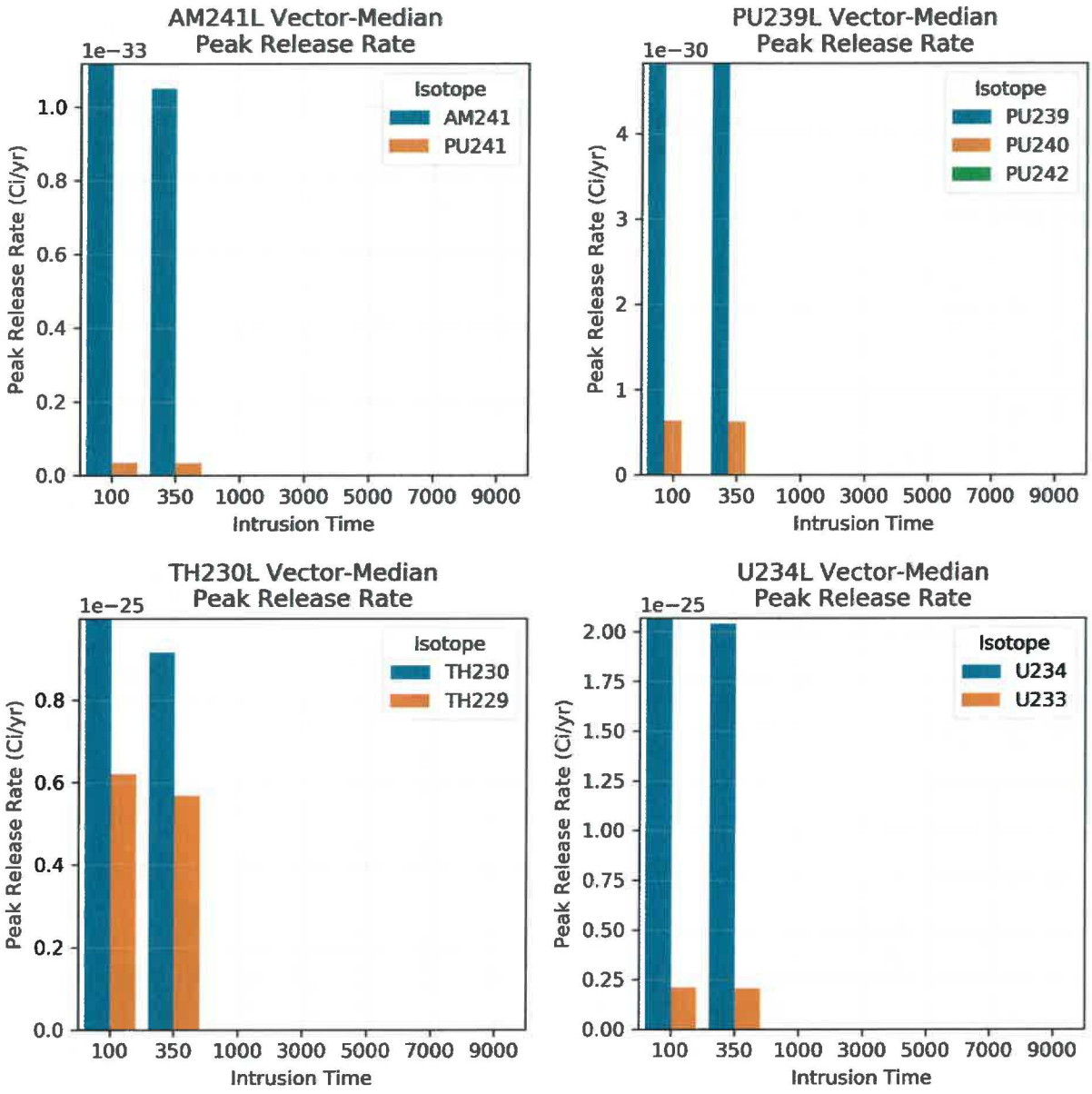

Figure 11-2: Median Peak Release Rate to the LWB

Table 11-2: Peak Release Rates through the Culebra from 100-yr Intrusions

Lumped Isotope	Isotope	Mean Peak Release Rate at the LWB[a] (Ci/yr)	Median Peak Release Rate at the LWB[a] (Ci/yr)
AM241L	AM241	3.56E-10	1.12E-33
	PU241	1.12E-11	3.40E-35
PU239L	PU239	1.08E-06	4.81E-30
	PU240	1.25E-07	6.32E-31
	PU242	1.33E-09	5.75E-33
U234L	U234	7.53E-05	2.07E-25
	U233	7.32E-06	2.07E-26
TH230L	TH230	1.08E-10	9.98E-26
	TH229	6.66E-11	6.19E-26

a: F_{max} in Equation 11-5

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12 CCDF Normalized Releases

This section describes the results of calculations performed using the CCDFGF code. In the typical course of WIPP PA calculations, the CCDFGF code uses the output of the other WIPP PA codes to produce a complementary cumulative distribution function (CCDF) compliance curve showing mean releases in EPA units. Releases in EPA units are not used for the dose calculations central to the NEPA20 analysis (Section 13), but CCDF results for the NEPA20 analysis are discussed here for completeness.

The CCDFGF code uses results from the calculations described in Sections 3 – 7, 9, and 10 above[11], along with the generation of random sequences of future events to generate complementary cumulative distribution function (CCDF) curves (Brunell 2019). Each individual CCDF summarizes the likelihood of releases across all futures for one vector of parameter values. The uncertainty in parameter values results in a distribution of CCDFs. In WIPP PA calculations performed for compliance calculations, the overall mean CCDF is compared to regulatory release limits. For the NEPA20 analysis, which is not a WIPP compliance calculation, the mean CCDF is presented along with regulatory release limits for illustrative purposes only. Unlike for the dose calculations described in Section 13, which only consider releases from a single intrusion at a selected time, the releases described in this section consider the cumulative releases due to multiple, random intrusions over 10,000 years.

12.1 Introduction

The performance assessment methodology accommodates both aleatory (i.e. stochastic) and epistemic (i.e., subjective) uncertainty in its constituent models (DOE 2019, Appendix PA). Aleatory uncertainty pertains to unknowable future events such as intrusion times and locations that may affect repository performance. It is accounted for by the generation of random sequences of future events, such as inadvertent drilling intrusions. Epistemic uncertainty concerns parameter values that are assumed to be constants and the constants' true values are uncertain due to a lack of knowledge about the system.

In WIPP PA, the PA models are executed for three replicates of 100 vectors, each vector being a realization resulting from a particular set of parameter values. Each realization consists of 10,000 stochastically derived futures, which are independently defined by the timings and locations of intrusion events (DOE 2019, Appendix PA). Overall means for each release mechanism, along with their 95 percent confidence limits, are presented below. Overall means are obtained by forming the average of all realizations and are calculated over all three replicates.

[11] Results in Sections 8 and 11 are included for the NEPA20 analysis, but are not a part of typical WIPP PA analyses. These two sections are necessary for the dose calculation portion of the NEPA20 analysis (Section 13) to calculate releases for a single intrusion at a selected time, rather than from multiple, random intrusions.

12.2 Results

Discussions of the four primary release mechanisms, i.e., 1) cuttings and cavings; 2) spallings; 3) releases from the Culebra; and 4) direct brine releases (DBRs)) are found in subsections below. Intermediate results that provide input into CCDFGF calculations have been discussed in Sections 3 – 7, 9, and 10 above. Plots of releases for individual release mechanisms[12] include means and their corresponding 95 percent confidence limits. Total normalized releases and a summary table of means and confidence limits for total releases at probabilities of 0.1 and 0.001 are presented in Section 12.3.

12.2.1 Cuttings and Cavings Releases

Cuttings and cavings releases depend on cuttings and cavings volumes and sampled waste stream concentrations. The assumed cuttings and cavings concentration for a given intrusion is based on waste stream volumes (which determine the probability of selecting a given waste stream) as well as waste stream concentrations over time–these are discussed in Section 3 above. For the NEPA20 analysis, Figure 12-1 shows the overall mean CCDF and 95 percent confidence limits for this release mechanism.

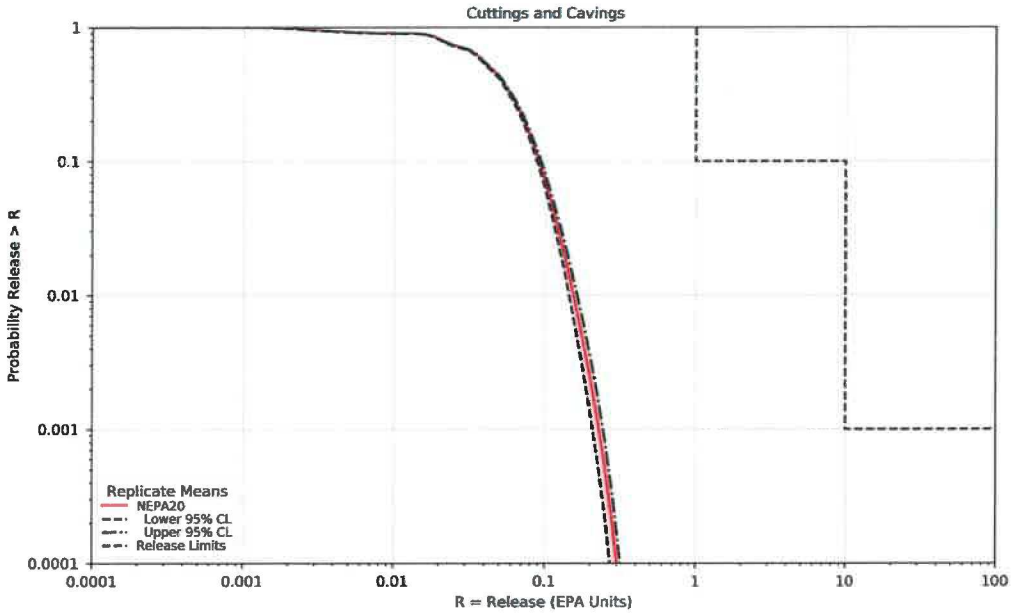

Figure 12-1: Overall Mean CCDFs for Cuttings and Cavings Releases

[12] The NUTS screening vectors registered a maximum cumulative release of 5E-11 EPA units through the marker beds at the land withdrawal boundary (LWB) for an undisturbed repository (scenario S1-BF) (replicate 1, vector 53). Since this release is many orders of magnitude smaller than average releases for disturbed scenarios, it is concluded that the undisturbed release is insignificant and can be omitted when considering the total releases from the repository in the NEPA20 analysis. Similarly, releases up the shaft have been omitted from consideration due to very small (maximum of 3E-111 EPA units) calculated releases.

12.2.2 Spallings Releases

Spallings releases depend on spallings volumes (which are a function of waste area pressure at the time of intrusion, discussed in Sections 4.2.1 and 6.2.2) and spallings concentrations (which are calculated as the average CH waste concentration at the time of intrusion, shown in Figure 6-3). Sampled parameter combinations that result in higher repository pressures generally correlate with higher spallings releases (Kicker 2019b). Figure 12-2 shows the overall mean CCDFs of spallings releases for the NEPA20 analysis.

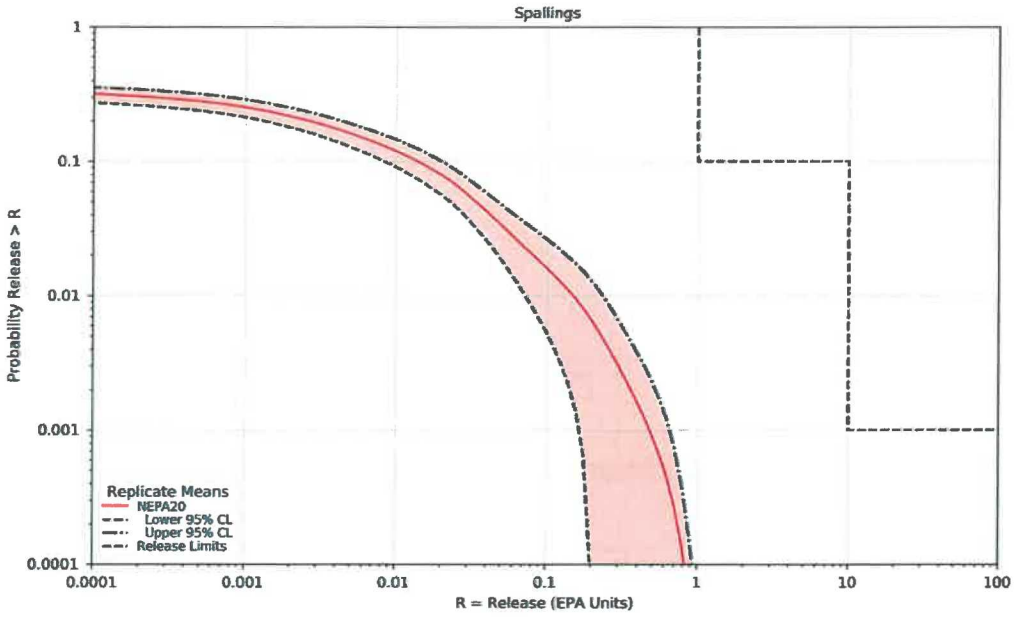

Figure 12-2: Overall Mean CCDFs for Spallings Releases

12.2.3 Releases from the Culebra

Releases by transport through the Culebra to the land withdrawal boundary are impacted by the amount of brine and radionuclides released to the Culebra via the borehole. Figure 12-3 shows the total releases to the Culebra, while Figure 12-4 shows releases from the Culebra. Figure 12-5 shows releases to and from the Culebra for the four radionuclides tracked in the Culebra transport model.

Although releases to the Culebra are dominated by Pu and Am, releases from the Culebra are due almost exclusively to U. For Pu and U, parameter values are selected according to the sampled reducing/oxidizing condition of the brine in the repository (50% of the realizations assume reducing conditions). For instance, matrix partition coefficients (K_{DS}) and diffusion coefficients for Pu(III) and U(IV) are used in reducing realizations, while properties for Pu(IV) and U(VI) are selected in oxidizing realizations (properties for Am(III) and Th(IV) are used in all realizations). The differences in mass transport among the four radionuclides can be attributed to differences in K_{DS} used in the Culebra flow model (Table 12-1). Values of K_D for U(VI) are approximately two orders of magnitude lower than for any other radionuclide and lower values of K_D are associated with faster transport through the Culebra. Diffusion coefficient values are similar among the

radionuclides and are therefore not expected to contribute much to the source of the observed differences between releases to and from the Culebra (Table 12-2).

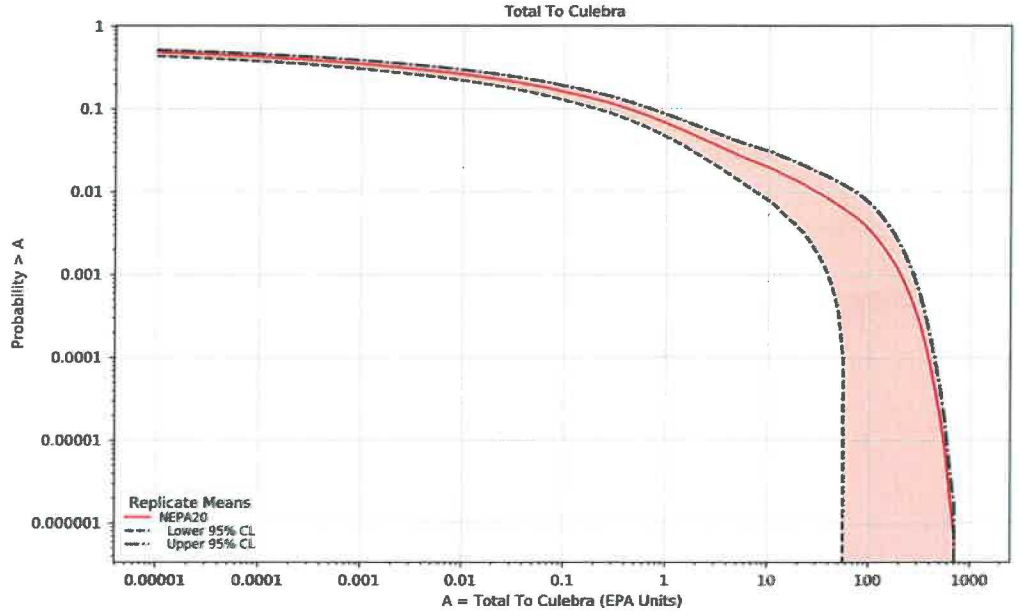

Figure 12-3: Overall Mean CCDFs for Releases to the Culebra

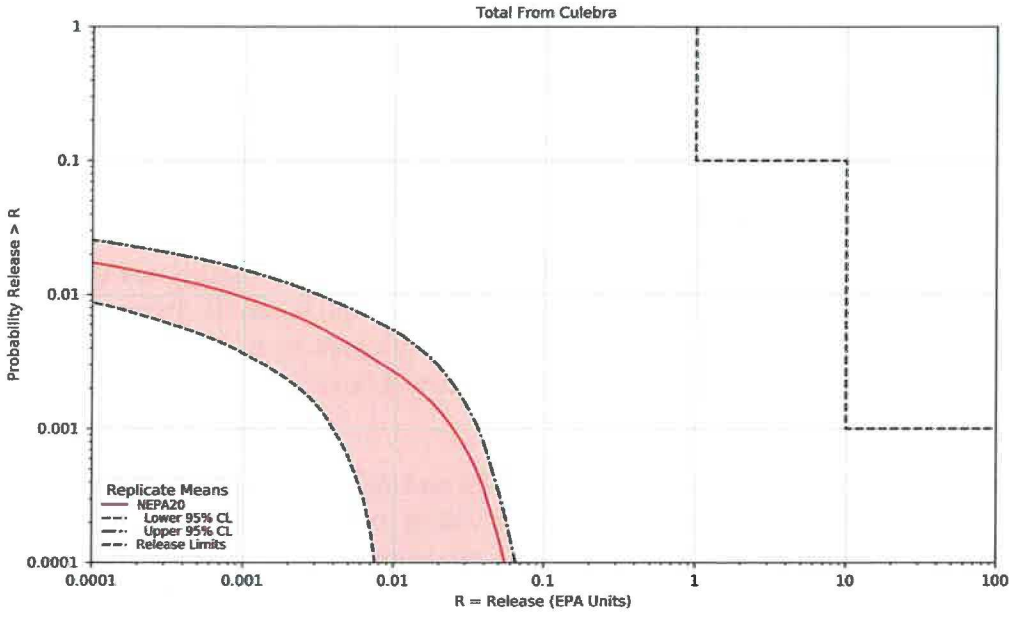

Figure 12-4: Overall Mean CCDFs for Releases from the Culebra

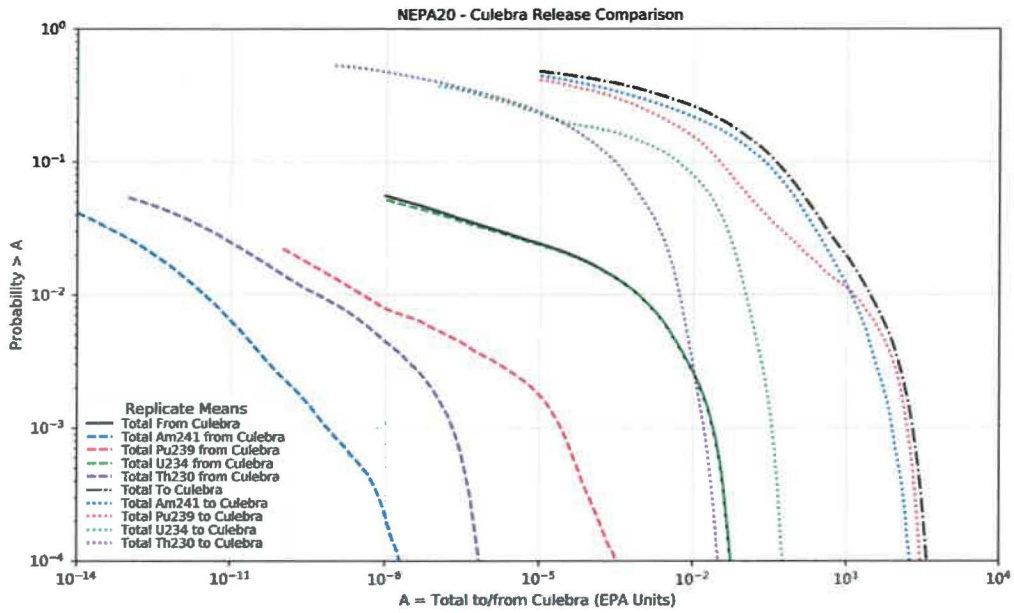

Figure 12-5: Mean CCDFs for Releases to and from the Culebra by Radionuclide

Table 12-1: Matrix Partition Coefficient (K_D) Parameters

Material	Property	Description	Matrix Partition Coefficient (m^3/kg)			Distribution
			Min.	Median	Max.	
AM+3	MKD_AM	Matrix Partition Coefficient for Am(III)	0.005	0.045	0.4	Loguniform
PU+3	MKD_PU	Matrix Partition Coefficient for Pu(III)	0.005	0.045	0.4	Loguniform
PU+4	MKD_PU	Matrix Partition Coefficient for Pu(IV)	0.0005	0.071	10	Loguniform
TH+4	MKD_TH	Matrix Partition Coefficient for Th(IV)	0.0005	0.071	10	Loguniform
U+4	MKD_U	Matrix Partition Coefficient for U(IV)	0.0005	0.071	10	Loguniform
U+6	MKD_U	Matrix Partition Coefficient for U(VI)	0.00003	0.00077	0.02	Loguniform

Table 12-2: Diffusion Coefficient Parameters

Material	Property	Description	Molecular Diffusion Coefficient (m^2/s)	Distribution
AM+3	MD0	Molecular Diffusion Coefficient for Am(III)	3.00E-10	Constant
PU+3	MD0	Molecular Diffusion Coefficient for Pu(III)	3.00E-10	Constant
PU+4	MD0	Molecular Diffusion Coefficient for Pu(IV)	1.53E-10	Constant
TH+4	MD0	Molecular Diffusion Coefficient for Th(IV)	1.53E-10	Constant
U+4	MD0	Molecular Diffusion Coefficient for U(IV)	1.53E-10	Constant
U+6	MD0	Molecular Diffusion Coefficient for U(VI)	4.26E-10	Constant

12.2.4 Direct Brine Releases

Direct brine releases depend on direct brine release volumes and radionuclide concentrations in the brine, as discussed in Sections 5 and 7. Figure 12-6 shows the resulting overall mean CCDFs of direct brine releases.

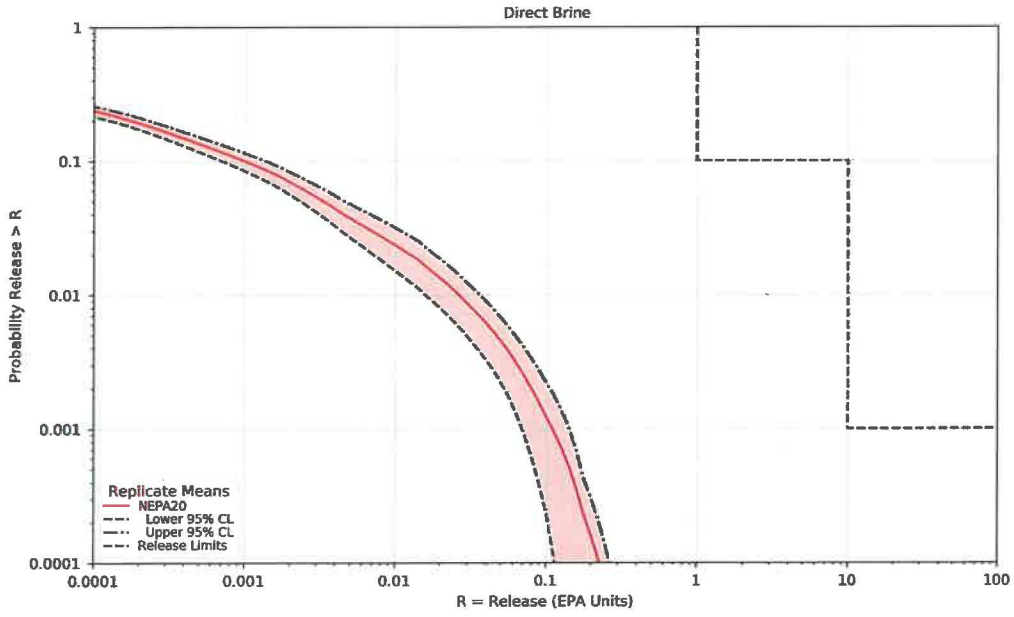

Figure 12-6: Overall Mean CCDFs for Direct Brine Releases

12.3 Total Releases

Total releases are calculated by summing the releases from each release pathway for each realization: cuttings and cavings releases, spallings releases, DBRs, and transport releases. CCDFs for total releases obtained in the 300 realizations (vectors) comprising replicates 1, 2, and 3 are plotted together in Figure 12-7— each CCDF curve represents the distribution of releases from 10,000 individual futures conditional on the values of parameters sampled for a single realization.

Mean CCDFs of the individual release mechanisms that comprise total normalized releases are plotted together in Figure 12-8, as well as the mean CCDF for the total release (average over all three replicates). As seen in Figure 12-8, total normalized releases are dominated by cuttings and cavings and spallings releases. Contributions to total releases from direct brine releases and Culebra transport are not dominant.

Figure 12-9 shows the overall mean CCDF is computed as the arithmetic mean of the mean CCDFs from each replicate and the 95% confidence interval about the overall mean CCDF computed using the Student's t-distribution and the mean CCDFs from each replicate. A summary of the statistics on the overall mean for total normalized releases is provided in Table 12-3.

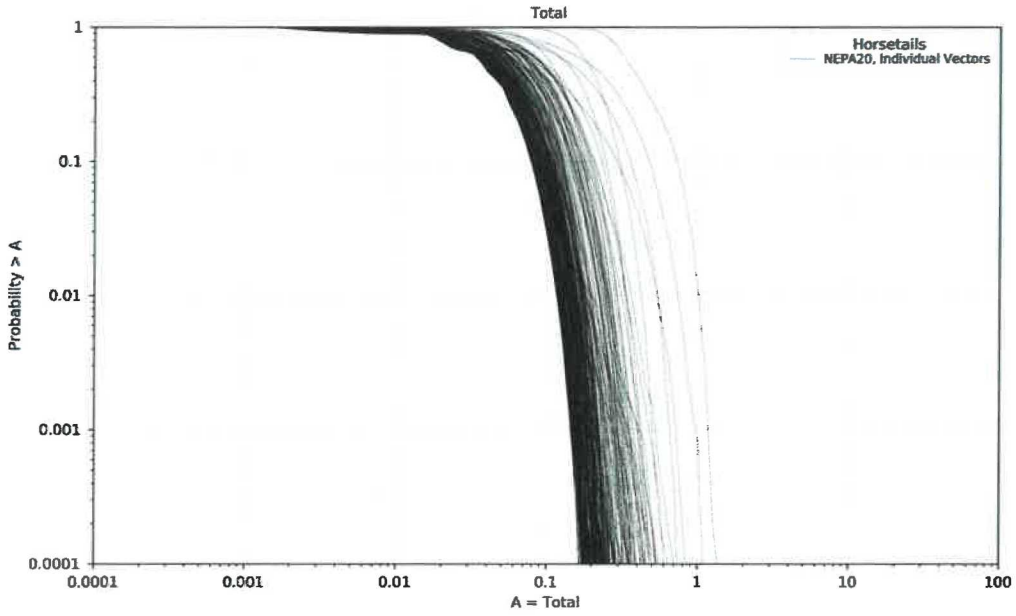

Figure 12-7: Total Normalized Releases, Replicates 1, 2, and 3

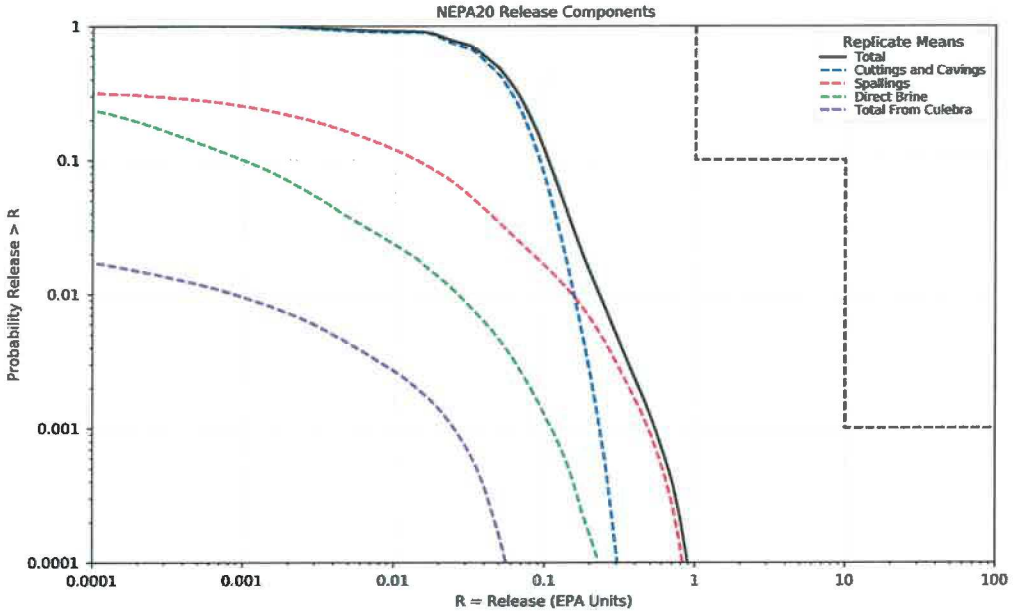

Figure 12-8: Comparison of Overall Means for Release Components

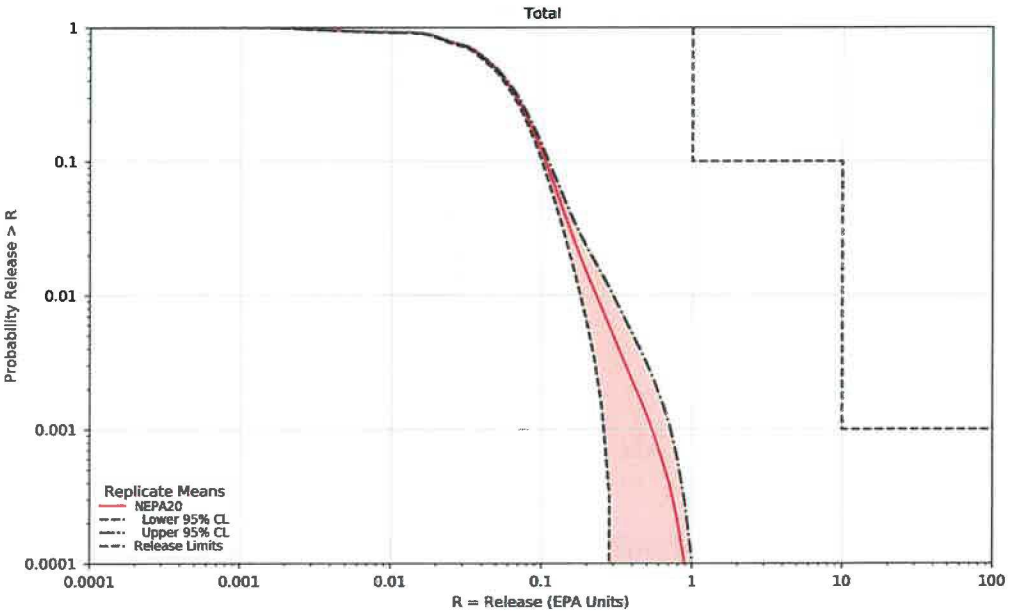

Figure 12-9: Overall Mean CCDF for Total Normalized Releases with Confidence Intervals

Table 12-3: The Overall Mean for Total Normalized Releases in EPA Units at Probabilities of 0.1 and 0.001

Probability	Mean Total Release	Lower 95% CL	Upper 95% CL	Release Limit
0.1	0.1058	0.1000	0.1112	1
0.001	0.5430	0.2633	0.7218	10

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13 Dose Calculations and Analysis

13.1 Introduction

This NEPA20 dose analysis generally follows the precedent set by SEIS-1997 (DOE 1997). Specifically, conservative estimates of a dose indicator to individuals, based on conservative PA calculations, are presented to demonstrate minimal and acceptable consequences. The locations of interest are at the boundary between the WIPP disposal system with the accessible environment: (1) the surface above the repository and (2) the surface at the land withdrawal boundary (LWB) 2.4-km from the center of the repository.

13.1.1 Undisturbed, Human Intrusion and Potash Mining Scenarios

The NEPA20 analysis examines the potential for radionuclide releases from a scenario without any disruption: the undisturbed scenario. The NEPA20 analysis also considers two hypothetical disruptive events that potentially result in human exposure: (1) inadvertent human intrusion by an exploratory drilling crew, and (2) potash mining above the closed repository.

In 40 CFR 191, EPA narrows the scope of the human intrusion to "inadvertent and intermittent intrusion by exploratory drilling for resources" (EPA 1993, App. C). The event occurs when enough degradation of the package has occurred such that driller would not easily recognize the existence of the repository. Although the event could occur far in the future, EPA specified use of the current state of human knowledge and technology;[13] For the dose calculations, a single intrusion is considered at a time when the radionuclide releases are greatest; hence, the potential dose after human intrusion is based on conservative assumptions.

The potash mining scenario consists of partial mining and full mining of potash reserves above the repository that influences the transport pathway to the land withdrawal boundary. Based on the PA analysis in CRA-2019, the full mining scenario results in larger releases through the Culebra. Dose calculations conservatively assume the full mining scenario occurs at the time of repository closure.

In summary, the conservative dose is evaluated for the undisturbed scenario and conditional on the human intrusion and full potash mining scenarios occurring, not the probability weighted dose.

13.1.2 Exposure Pathways after Human Intrusion

Three hypothetical exposure pathways after human intrusion are considered (Figure 13-1): (1) geologist examining contaminated drill cuttings, cavings, and spallings debris at surface, (2) worker exposed to radionuclide contamination in drilling debris at the surface, and (3) rancher

[13] How EPA treats the uncertainty associated with the human disruptive scenario evolved between 40 CFR 191 for WIPP and 40 CFR 19, the site-specific regulation for the proposed Yucca Mountain repository. The National Research Council of the National Academies recommended in 1995, and EPA concurred in 40 CFR 197, that a licensee evaluate only the potential consequences (not probability) of a few selected situations of inadvertent human intrusion and thus, not include the human intrusion scenario class in the probabilistic dose calculations (NA/NRC 1995).

consuming cattle that drinks water from stock pond supplied by well withdrawing contaminated water at the land withdrawal boundary. The geologist, worker disposing of drilling debris, and the rancher are not real people, but represent individuals in hypothetical future scenarios. The same three human exposure pathways were examined in the SEIS-1997 (DOE 1997). However, the drilling debris pathway in NEPA20 differs conceptually from SEIS-1997 because of changes in drilling practices, as discussed in Section 14.5.1.

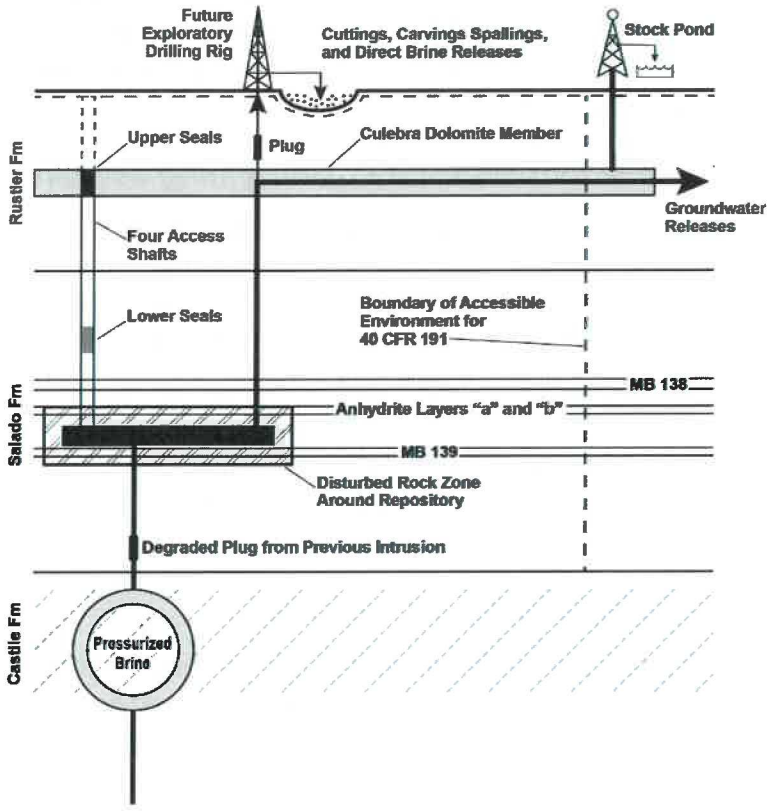

Figure 13-1: Hypothetical Release of Radionuclides by Drilling (Cuttings, Spallings, Direct Brine Release and Culebra Transport) and Subsequent Exposure of (1) Geologist Examining and (2) Worker Disposing of Drilling Debris or (3) Rancher Who Consumes Cattle that Drink Contaminated Water (Rechard 1996, Fig. 4.2-4).

13.1.3 Radionuclide Inventory

The radionuclide inventory in CH-TRU and RH-TRU containers is that developed specifically for NEPA20 as described in Section 2 (Van Soest 2019). The inventory of polychlorinated biphenyl chemicals (PCBs) and Resource Conservation and Recovery Act (RCRA) materials and their potential hazards is discussed elsewhere (Brunell 2020b).

13.1.4 Dose Calculation

GENII V.2.10.2 is used to evaluate biological dose conversion factors for the drilling debris and rancher pathways. GENII is widely used to conduct dose assessments. It was used for SEIS-1997. The current version was downloaded from the Nuclear Regulatory Commission (NRC) RAMP system and the sample problems run to demonstrate correct installation. The dose calculation

method chosen in GENII was that specified in Federal Guidance Report 12 for external doses (Eckerman et al. 1993) and Federal Guidance Report 13 for general environmental exposure. Federal Guidance Report 13 is suggested for risk analysis for environmental impact statements (Eckerman et al. 1999).

GENII does not evaluate external dose from a point source. Rather a separate point source biological conversion factor is used for the pathway where a geologist is examining a specimen.

13.1.5 Use of NEPA20 PA Results

For the dose calculations, a single intrusion is considered; the intrusion time is selected when the radionuclide releases are greatest. The potential dose to a hypothetical geologist working with drilling debris is conditional on an intrusion into the repository at 100 years.

The potential dose to a hypothetical rancher is conditional on an intrusion at 100 years into the repository and underlying brine pocket (i.e., S2-BF and S3-BF in Section 4).

For the potential dose to a hypothetical worker exposed to drilling debris, the intrusion is assumed to encounter pressurized brine in the repository from a previous intrusion into the Castile Formation below the repository, since radionuclide releases are conservatively larger for these cases (i.e., S2-DBR and S3-DBR in Section 8). To elaborate, the NEPA20 PA results from scenarios S2-DBR and S3-DBR represent releases from a second repository intrusion, not an intrusion into an undisturbed repository. These results are used to maximize potential DBRs and spallings releases. Cuttings and cavings releases are independent of repository conditions and thus would be the same for a previously undisturbed repository.

13.2 Dose Measure

The measure of the dose indicator in the NEPA20 analysis is the annual committed effective dose equivalent (hereafter, dose or $D_{total}(t;\mathbf{p})$), defined as the dose received by an individual from the sum of external exposure $D_{external}(t;\mathbf{p})$ and internal exposure $D_{internal}(t;\mathbf{p})$ through ingestion and inhalation of radionuclides over an exposure period, using methods and weighting factors for organ tissue radionuclide and radiation types of the International Council for Radiation Protection (ICRP). That is,

$$D_{total}(t;\mathbf{p}) = D_{internal}(t;\mathbf{p}) + D_{external}(t;\mathbf{p}) \tag{13-1}$$

where

$$\bar{D}_{internal}(t;\mathbf{p}) = \sum_{r}^{n_r} f_r^{BDCF}(\mathbf{p}) C_r^{source}(t;\mathbf{p}) \tag{13-2}$$

where f_r^{BDCF} is the biologic dose conversion factor for radionuclide r; n_r is number of radionuclides contributing to the release; and $C_r^{source}(t;\mathbf{p})$ is the source concentration; $\mathbf{p}$ is the set of the model parameters $\mathbf{p}= \{\varphi_1,.., \varphi_n,..,\varphi_{nP}\}$, and t is time.

The exposure period is a function of the exposure pathway: 1 hour for geologist examining waste, 21 days for crew member working around drilling debris; and 1 year for rancher consuming beef from cattle that has been drinking water contaminated with radionuclides. The length of time for

evaluating the internal committed dose is 50 years, which is consistent with the Individual Dose Requirement in 40 CFR 191 and past SEIS analysis. The period of interest is the maximum dose received over the 10,000-year regulatory period of 40 CFR 191.

The $C_r^{source}(t;\mathbf{p})$ in Eq. (13-2) can be estimated by a system model; that is

$$D_{internal}(t;\mathbf{p}) = \sum_{r}^{n_r} \frac{f_r^{BDCF}(\mathbf{p})}{Q^{well}} \mathcal{M}_r(t;\mathbf{p}) \tag{13-3}$$

Where $\mathcal{M}_r(t,\mathbf{x};\mathbf{p})$ is the system model that calculates the total mass of radionuclides crossing the boundary of the geologic disposal system; and Q^{well} is the dilution at a withdrawal well.

The system model $\mathcal{M}_r(t,\mathbf{x};\mathbf{p})$ is that used in the PA. To elaborate, in the EPA radiation protection standards applied at WIPP (40 CFR 191), the primary health indicator in 40 CFR 191 is the cumulative release of radionuclides (R) at a compliance boundary in EPA units (EPA 1985a):

$$R_{total}(\mathbf{p}) = \sum_{r=1}^{n_r} \frac{1}{f_w L_r} \int_0^{\mathfrak{I}} \mathcal{M}_r(t;\mathbf{p}) dt \tag{13-4}$$

where f_w is a waste unit factor (WUF, Section 3) equal to $\Sigma\, W_r/10^6$ Ci; W_r is total activity (Ci) in the repository of α-emitting transuranic (TRU) radionuclides r with half-life ($t_r^{1/2}$) $\geq$ 20 years; L_r is the regulatory release limit (Ci) for radionuclide r specified in 40 CFR 191; and $\int_0^{\mathfrak{I}} \mathcal{M}_r(t;\mathbf{p})dt$ is cumulative release over the regulatory period $\mathfrak{I}$ (10,000 yr) for radionuclide r at the boundary of the disposal system. The system model $\mathcal{M}_r(t,\mathbf{x};\mathbf{p})$ in Eq. (13-4) and Eq. (13-3) are the same, although the implications of the cumulative integration over 10,000 yr and the normalizing factors differ between Containment Requirements in §191.15 and Individual Protection Requirements in §191.16. A summary of the approaches taken for dose measures for the NEPA20 analysis is provided in Table 13-1.

13.2.1 Dose Limits

The dose evaluations of NEPA20 are compared with current recommended ICRP limits to demonstrate minimal and acceptable consequences. The recommended dose limits are 1 mSv/y to members of the public and 20 mSv/y to workers, where the latter dose may be averaged over 5 years (ICRP 2007, Table 6). For waste disposal, ICRP recommends a goal of less than 0.3 mSv/y (ICRP 2007, Section 260).

Table 13-1: Summary of Approach for Dose Measure

Health Indicator and Measure	Approach
Dose measure	Committed effective dose equivalent, defined as the committed dose over committed period from specified period of external exposure and ingestion of radionuclides by an individual.
Dose limits for radionuclides	(a) 1 mSv for members of public (b) 20 mSv/y averaged over 5 years for workers
Exposure/uptake for three locations of interest	(a) 1 hour external exposure for geologist examining 524-cm^3 drilling debris (SEIS-1997 assumption) (b) 168 hours (21 8-hour workdays) external exposure when working around contaminated drilling debris (SEIS-1997 assumption) (c) 100 mg/d internal ingestion of cutting debris (SEIS-1997 assumption) (d) 1-year internal consumption of 42 kg beef from steers that ingested contaminants from stock well
Dose commitment period	50 years for adult
Period of interest	10,000 years
Locations of interest	(a) Doses at surface through shafts and at Land Withdrawal Boundary (LWB) through marker beds (b) Doses at surface at exploratory drilling operation from one inadvertent intrusion (i) examining core and (ii) exposure from cuttings, cavings, spallings, and direct brine release debris (c) Dose to rancher consuming stock that drink from contaminated well where concentration estimated from cumulative mass crossing LWB from one intrusion in average brine released
Consideration of inadvertent human disruption	(a) Contaminated brine released to surface through shafts or to LWB (b) Radionuclides decayed to time of intrusion (c) Cuttings, cavings, spallings, and direct brine release to disposal (d) Cuttings, cavings, and spallings release for geologist observation (e) Brine flow to Culebra with full potash surface mining
Hazardous waste category*	Radionuclides
Four methods of calculating hazard mass	Two deterministic calculations using mean and median outputs of simulations from NEPA20 PA analysis at the three specified locations of interest. For comparison with SEIS-1997, two additional calculations using mean and median PA input parameters are also assessed
Calculation tools	(a) GENII v2.10.2 to calculate biological dose conversion factor for radionuclides for 2 exposure pathways (drilling crew and rancher) (b) Point source factors of biological dose conversion factor are used for external exposure from examining chips sieved from drilling mud

Health Indicator and Measure	Approach
*Health impact of PCBs and heavy metals is evaluated in a separate analysis (Brunell 2020b)	

13.3 Central Tendency as Measure of Dose

In 40 CFR 191, EPA invoked "reasonable expectation" as the standard of proof for compliance with EPA limits. Reasonable expectation connotes a flexible standard of proof and use of central estimates when encountering unknowns. For the Individual Protection Requirements, EPA invoked "best estimate" for comparison with dose limits (EPA 1985b, p. 38088): "The Agency assumes that compliance can be determined based upon 'best estimate' predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher)." Following the spirit of the 40 CFR 191, mean and median dose is evaluated for the proposed action using the mean and median outputs calculated from all simulation vectors of the NEPA20 PA described in Sections 3-12.

13.3.1 Mean and Median Results from PA

Two primary dose calculations are made, based on the mean (i.e., $\mathcal{E}\{\mathcal{M}_r(t,\mathbf{x};\mathbf{p})d\mathbf{x}\}$) and median results from the PA process models, for each of the three pathways. To elaborate, the expected value of the internal dose $\bar{D}^{internal}(t)$ is

$$\bar{D}^{internal}(t;\mathbf{p}) = \mathcal{E}\{D^{internal}(t;\mathbf{p})\} = \int_{\Omega} D^{internal}(t;\mathbf{p})g(\mathbf{p})d\mathbf{p} \tag{13-5}$$

where $\mathcal{E}\{\sim\}$ is the expectation operator defined by the integral, $g(\mathbf{p})$ is the joint probability density function for the model parameters $\mathbf{p}= \{\varphi_1,.., \varphi_n,..,\varphi_{nP}\}$, and Ω is the parameter space. Substituting, the definition of $D_{internal}(t;\mathbf{p})$ (Eq. (13-3)) into Eq. (13-5), the mean dose is evaluated from the mean results of the system model $\mathcal{E}\{\mathcal{M}_r(t;\mathbf{p})\}$

$$\bar{D}^{internal}(t;\mathbf{p}) = \sum_{r}^{n_r} \frac{\mathcal{E}\{f_r^{BDCF}(\mathbf{p})\}}{Q^{well}} \mathcal{E}\{\mathcal{M}_r(t;\mathbf{p})\} \tag{13-6}$$

$$= \sum_{r}^{n_r} \frac{f_r^{BDCF}(\bar{\mathbf{p}})}{Q^{Well}} \mathcal{E}\{\mathcal{M}_r(t;\mathbf{p})\} \tag{13-7}$$

Because $f_r^{BDCF}(\mathbf{p})$ is a linear function, $\mathcal{E}\{f_r^{BDCF}(\mathbf{p})\} = f_r^{BDCF}(\bar{\mathbf{p}})$ where $\bar{\mathbf{p}}$ is the vector of mean values of the parameters. Thus, the parameter values of $f_r^{BDCF}(\mathbf{p})$ are fixed at a single value in this analysis with no uncertainty.

Similarly, the median dose is evaluated from the median results of the system model $50\%\{\mathcal{M}_r(t;\mathbf{p})\}$ where the parameters of the biological dose conversion factor $f_r^{BDCF}(\mathbf{p})$ are again fixed at a single value in this analysis.

13.3.2 Dose from Mean and Median Parameter Values

The system model $\mathcal{M}_r(t;\mathbf{p})$ is not linear in Eq. (13-7); hence, the mean (or median) of all 300 vectors of cumulative releases is not the same as the cumulative release using mean (or median) model parameters (i.e., $\mathcal{E}\{\mathcal{M}_r(t;\mathbf{p})\} \neq \mathcal{M}_r(t;\bar{\mathbf{p}})$). Two additional supplementary PA calculations were made using mean and median PA parameter values ($\bar{\mathbf{p}}$ and $^{50\%}\mathbf{p}$)in the system model. Dose was calculated for these supplementary PA calculations to compare with the primary dose calculations and to compare with previous SEIS-1997 results, which used mean and median parameters. That is, the SEIS-1997 only reported doses using the 50th percentile (median) PA parameters and 75th percentile parameters in the system model where the latter 75% percentile is often but not always similar to the mean (e.g., the mean and 75th percentile are similar for a log-uniform distribution).

In the supplemental analysis, parameters that are not varied in the PA analysis are fixed at the same value as in the PA analysis. The majority of parameters varied in the PA are material-property parameters related to the system model. When a distribution for the material-property parameters has been defined, the mean and median values are extracted from the database for use in the supplemental calculations. However, selection of a representative value for a few parameters needs further discussion.

13.3.2.1 CPR Degradation Probability

The parameter that represents the probability of plastics and rubber biodegradation in the event of microbial gas generation takes on a value of 1 with 75% probability; hence, the parameter value for both the mean and median vectors is set to 1.

13.3.2.2 Humid Biodegradation Rate for Cellulose

The parameter that represents the humid biodegradation rate for cellulose must be equal or less than the inundated biodegradation rate for each realization. Therefore, the mean and median of the humid biodegradation rate is set to the mean and median of inundated biodegradation rate.

13.3.2.3 Relative Permeability Model Number

Experimental data for the marker beds in the Salado Formation fit either the modified van Genuchten-Parker model or the Brooks-Corey model of relative permeability in BRAGFLO calculations; thus, a choice parameter weights each model equally. However, the Brooks-Corey model is used more often for other materials, so for this analysis, the choice parameter is set to the Brooks-Corey mode for the mean and median parameter runs.

13.3.2.4 Oxidation State of Actinides

Actinide solubility is varied as a function of oxidation state and usually found to be important in explaining uncertainty in the results. In the PA, Pu, U, and Np radionuclides are defined by two oxidation states with equal probability. The reduced state leads to higher calculated releases based on higher solubilities associated with Pu(III) compared to Pu(IV). A value of 0.25 is used for the mean and median to conservatively force the reduced state and avoid ambiguity of the 0.5 value, which is the mean and median of the parameter distribution. As a result, oxidation states are assumed to be Pu(III), U(IV), and Np(IV) for calculations using median or mean input parameters.

13.3.2.5 Climate Scenario

The parameter for climate scenario index is bimodal that models two different climate scenarios: (1) continued Holocene weather patterns; and (2) climate change. The mean value falls between the two bimodal distributions with zero probability. The climate change model is conservatively

assumed, and an average of the right side of the distribution is taken such that a value of 1.75 is used for the mean and the median.

13.3.2.6 Transmissivity Field

The transmissivity field of the Culebra influences both the path and rate of contaminant movement to the accessible environment. Uncertainty in transmissivity is expressed by 100 realizations of transmissivity fields. The travel time to the LWB calculated by the DTRKMF code is a scalar measure of each field used to give the flow fields an ordering for no-mining scenarios adjusted for a 4-meter-thick aquifer.

A histogram of the travel times is shown in Figure 13-2. The mean particle travel time is 1.11E+04 years; the closest realization to that value is realization 082. The median particle travel time is 7.35E+03 years, calculated as the mean of the two middle realizations. The lower of the two realizations, realization 631, was chosen to represent the median, which has a travel time of 7.32E+03 years.

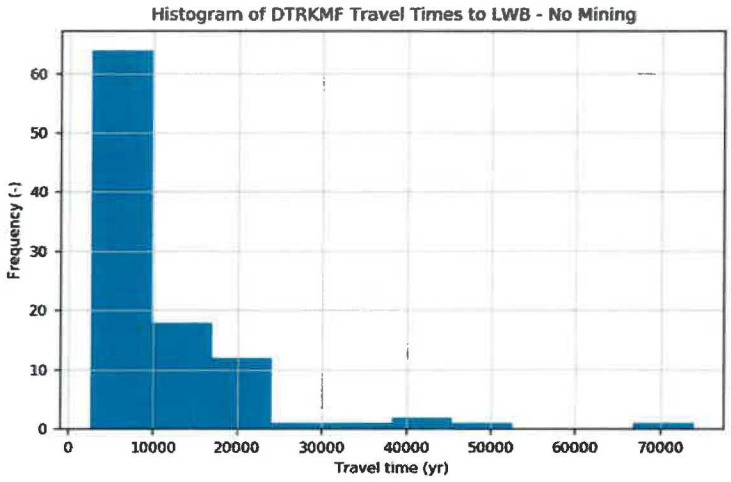

Figure 13-2: Distribution of Particle Travel Time to the Land Withdrawal Boundary

13.4 Undisturbed Pathway

The undisturbed scenario is considered in NEPA20 (Section 9.2) and was considered in SEIS-1997. In NEPA20, 83 of the 100 vectors of replicate 1 of the undisturbed scenario (S1-BF-r1) show no brine from the repository reaching the Culebra through the shafts.[14] The median of all vectors had no brine flow and only 37.2-m^3 of brine passes through the shaft for the mean of all results over 10,000 years. Furthermore, 95 of the 100 vectors of S1-BF-r1 had cumulative brine

[14] Selection of replicate 1 for this analysis is based on a comparison of results of the three replicates, which shows that replicate 1 is representative of the three replicates. Averaged pressure and saturation in the repository waste panel, which determine releases, are fairly similar in the three replicates. However, replicate 3 has noticeably lower average cumulative brine flow away from the repository than replicates 1 and 2; thus, replicates 1 and 2 result in potentially higher radionuclide migration. Replicate 1 was used for convenience.

releases to the LWB less than 0.1 m^3. Only small amounts of brine flows to the LWB for the median over 10,000 years: a cumulative brine volume of 1.25×10^{-3} m^3 and 4.75×10^{-3} m^3, respectively. The mean cumulative brine reaching the LWB is somewhat larger at 335 m^3 and dominated by only four vectors.

Concentration at the LWB or at the Culebra of a nonsorbing tracer with initial concentration of 1 kg/m^3 at the repository is less than 10^{-7} kg/m^3 (7 orders of magnitude less than the initial fixed concentration) except for one vector (Section 9.2). The mean and median of the tracer concentration at the LWB are all less than 10^{-7} kg/m^3. To elaborate, radionuclide concentrations in the repository are reduced by at least 7 orders of magnitude, prior to any dilution from a withdrawal well and any reduction provided by solubility control and adsorption.

Consequently, doses up the shaft and to the LWB in the undisturbed scenario for the mean and median are practically zero because no quantifiable releases occur

13.5 Geologist Pathway

13.5.1 Pathway Description

The short-term result of a hypothetical inadvertent intrusion into the closed WIPP repository far in the future by an exploratory drilling operation is entrainment of radionuclides and hazardous metals into the drilling fluid and their release into a storage tank at the surface. The potential dose received by the members of the hypothetical drilling operation is dependent on the waste inventory, not characteristics of the disposal system since both engineering and geologic barriers are breached by the hypothetical drilling (NRC 2001, p. 55761). In turn, the potential dose is dependent upon the time of hypothetical intrusion and assumptions of how exposure occurs at the surface.

To reach the depth of the repository, mineral exploration may be searching for hydrocarbons using a rotary oil drilling rig. In this pathway, a hypothetical geologist or mud logger is examining chips sieved from the drilling mud, not an intact core specimen. Based on current practices, drilling would be proceeding rapidly through the Salado salt formation to deeper horizons of interest for hydrocarbons and so the time-consuming processing of removing the drilling string to insert a coring bit and string is not assumed.

The uncertainty in drilling debris is dominated by the waste stream intersected by the drill bit. Beyond the waste stream uncertainty, the fixed volume of examined chips assumed with this pathway eliminates any uncertainty related to sampled PA parameters. Therefore, the doses calculated for mean and median parameter values are the same as the doses for mean and median of releases and are not displayed here separately.

13.5.2 Radionuclide Source

In the hypothetical geologist pathway, the radionuclide source comprises solid material released as the chips releases from cuttings, cavings, and spallings, and depends upon the particular waste stream intersected by the drilling. In the PA, the probability of intersecting a particular waste stream is proportional to volume. As described in Section 3, the mean dose calculation uses the mean radionuclide concentrations in the full CH and RH waste inventories, determined from the total anticipated radionuclide inventory divided by the total authorized volume of CH and RH waste, 168,536 m^3 and 7076 m^3, respectively, for the total of 175,612 m^3 in Table 3-1 or 6.2×10^6

ft^3. The median concentration for each radionuclide is that of the waste stream with the median rank of the total radionuclide concentration (Table 13-2) (see also Table 3-6 and Table 3-7).

13.5.3 Time of Intrusion

The external dose received by the geologist is sensitive to the time of intrusion since high activity radionuclides are short lived. Dose is reported here for an intrusion time of 100 years (Table 13-2). To compare with the SEIS-1997, dose is also calculated at an intrusion time of 400 years and 300 years. EPAUNI outputs the inventory at 100, 175, 350, and 1000 years in Section 3, so mean results at 300 years and median results at 400 years are interpolated.[15]

Table 13-2: Mean and Median Radionuclide Inventory Concentration of All Waste Streams at 100, 300, and 400 Years

Isotope	Mean of All Waste streams				Median Waste Stream			
	100 y		300 y		100 y		400 y[a]	
	CH (Ci/m^3)	RH (Ci/m^3)	CH (Ci/m^3)	RH (Ci/m^3)	CH (Ci/m^3)	RH (Ci/m^3)	CH (Ci/m^3)	RH (Ci/m^3)
^{241}Am	1.67E+1	1.62E+0	1.22E+1	1.18E+0	2.14E+0	8.15E-1	4.49E-1	2.13E-1
^{244}Cm	9.76E-4	5.85E-2	1.59E-5	9.51E-4	0	0	0	1.89E-5
^{137}Cs	2.89E-4	1.88E+0	2.92E-6	1.89E-2	0	5.37E-3	0	6.7E-11
^{238}Pu	5.27E+0	1.84E+0	1.36E+0	4.74E-1	3.04E-1	3.46E-2	3.36E-3	2.11E-3
^{239}Pu	5.19E+1	6.13E-1	5.16E+1	6.10E-1	5.68E-1	5.39E-1	1.57E+0	2.82E-1
^{240}Pu	1.28E+1	4.95E-1	1.26E+1	4.85E-1	4.80E-1	2.07E-1	3.52E-1	5.36E-1
^{241}Pu	1.46E-1	2.20E-2	1.13E-3	1.71E-6	1.86E-2	9.96E-3	4.53E-8	8.57E-9
^{90}Sr	4.11E-4	1.38E+0	3.51E-6	1.18E-2	0	3.86E-3	0	6.91E-13
^{233}U	7.07E-4	3.61E+0	7.07E-4	3.60E-3	3.55E-9	1.14E-4	3.95E-6	1.08E-9
^{234}U	8.76E-3	2.92E-3	1.02E-2	3.41E-3	2.73E-4	2.47E-5	2.20E-5	5.14E-4
[a]Median waste stream is different at 100 y and 400 y when median ranking is determined by total Ci/m^3								

13.5.4 Geologist Pathway Parameters

The hypothetical geologist pathway involves only external exposure from chips of waste collected from the drilling mud at the shaker, which sieves out drilling cuttings. The amount of material that is extraneous material mixed with the waste in the sample depends upon the (1) the proportion of container, waste, and disposal room material extracted from the repository, (2) the material entrained with the repository material as the drilling mud carries the debris to the surface in the annulus of the borehole, and (3) the possibility of further mixing of extraneous material at the surface prior to sampling by the geologist. In SEIS-1990, the geologist exposure was roughly

[15] Interpolating mean values is straightforward and fairly accurate. Interpolating median values is not possible because the median is determined by ranking the waste streams at a particular time. Nonetheless, here an interpolation between 350 and 1000 years is used to approximate the median at 400 years, even though there would not be a waste stream at 400 years that had these particular values.

estimated from the average contents of three CH-drums. In SEIS-1997, the geologist was presumed to have obtained the sample from the mud pit, but the amount of extraneous material was not specified. In the NEPA20 analysis, the geologist is following the current practice of obtaining the sample at the shaker and so there is no mixing with extraneous material in the mud pit. Rather, the only extraneous material is from (1) the container and (2) material entrained in the drilling mud as it travels up the drill string annulus from the repository to the surface. Here, it is assumed that other cavings material entrained while traveling up the drill string annulus represents 90% of the material volume in the specimen, whether the sample is from an RH or CH container. As noted in Section 13.3.1, Eq (13-7), the biological dose conversion factor is linear and so doses with other amounts of well debris volume can readily be estimated.

Container material volume comprises a fraction of container total volume. For a thin-shelled CH container, container materials represent ~2.9% of the container total volume. Thus, for CH waste the total dilution is 9.7% (i.e., (100%-90%)*(100%-2.9%)).[16] The RH canister material represents 12% of the total volume for an RH canister that is 0.635 cm thick, with 66 cm outer diameter, and 306 cm long including 21 cm long with internal volume of 0.940 m^3. In the future, however, most RH waste will come in shielded containers. For a shielded container, container material represents 38% of the volume comprising a 0.437 cm thick outer shell, 2.54 cm lead shell, and 0.357 inner shell, 58.4 outer diameter, and 90.8 outer height. Thus, for RH waste the total dilution of the waste material concentration listed in Table 13-2 is 6.2% (i.e., (100%-90%)*(100%-38%)).

The GENII code estimates external exposure from large surface area such as water bodies or contaminated fields; it does not estimate dose from a localized area such as a small geologic specimen or other point source. Hence, dose conversion factors where developed separately for examining a 524 cm^3 specimen of chips and debris (approximated as a 5 cm sphere) for 1 hour (Table 13-3 and Table 13-4). The specimen volume is the same as SEIS-1997.

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[16]Because the potential dilution is so much larger for the large volume drilling debris, an alternative approach is taken for the drilling debris pathway (Section 6). In the drilling debris pathway, the mass of radionuclides releases is determined from radionuclide concentration in the repository times the volume of the cuttings, cavings, spallings, and brine released. The radionuclide concentration in the drilling debris is then determined by dividing the mass by the large volume of drilling debris (Table 13-10). In Section 13.6 0.11 m^3 of cuttings, cavings, and spallings is removed from the repository during an intrusion for mean conditions (Table 13-9). Under the assumptions of this Section 13.5.4 , the 0.11 m^3 of debris represents 10% of the drilling debris; hence, for the geologist pathway a reasonable, but conservative ~1.1 m^3 of other material from the walls of the borehole is assumed to be entrained in the drilling fluid and mixed with the repository waste as it travels ~600 m from the repository horizon up the drilling annulus to the surface.

Table 13-3: Dose Parameters of Geologist Pathway

Geologist Pathway Parameter	Value
External exposure time (h) (SEIS-1997 assumption)	1
Specimen volume (cm^3) (SEIS-1997 assumption)	524
Distance from specimen (m)	1

Table 13-4: Biological Dose Conversion Factors for External Exposure to 5-cm Sphere for 1 Hour (Rechard 1995, Table 14.2)

Isotope	BDCF (Sv/y per Bq/m^3)
^{241}Am	5.84E-15
^{244}Cm	3.08E-17
^{137}Cs	3.03E-13
^{238}Pu	3.7E-17
^{239}Pu	4.36E-17
^{240}Pu	3.63E-17
^{241}Pu	7.71E-23
^{90}Sr	7.49E-13
^{233}U	8.71E-15
^{234}U	6.31E-13

13.5.5 Geologist Pathway Dose

The mean dose to a geologist examining cuttings, cavings, and spallings contaminated with radionuclides is summarized in Table 13-5. The greatest risk is from an intrusion at 100 years[17] that encounters RH waste with a dose of 3.8×10^{-3} Sv/y and a risk of cancer fatality of 1.9×10^{-4}-y^{-1} (Table 13-5), which is less than the 20×10^{-3} Sv/y limit ICRP suggests for workers but greater than the 10^{-3} Sv/y limit ICRP suggests for the public. The primary contributors to dose are ^{137}Cs

[17] The EPA Standard, 40 CFR 191, assumes administrative passive controls prevent intrusion prior to 100 years. A similar assumption is made here that prevents an intrusion before 100 years (actually 100 years plus a few days).

and ^{90}Sr. These radionuclides rapidly decay and the dose drops 2 orders of magnitude to 5.5×10^{-5} Sv if the drilling intrusion occurs at 300 years (as used in SEIS-1997). Little or no ^{137}Cs and ^{90}Sr is present in CH-waste and so the primary contributors are ^{241}Am and Pu. By 300 years, the mean dose of 2.9×10^{-4}Sv from intercepting a CH container is greater than the mean dose from intercepting an RH shielded container.

The median dose is 4.6×10^{-5} Sv/y or a risk of cancer fatality of 2.3×10^{-6}-y^{-1} at 100 years for solids from CH waste, but the median dose of 2.2×10^{-5} Sv/y from an RH shielded container is fairly similar (Table 3-6 and Table 3-7). The external dose in NEPA20 is similar to the 10^{-5} Sv/y estimated for the geologist in SEIS-1990, when examining waste from three CH-TRU drums brought to the surface in cuttings (DOE 1989, Lappin et al. 1989, p. 7-7). However, the median dose in SEIS-1997 is 3 orders of magnitude smaller at 5.7×10^{-8} Sv/y, since the specimen was assumed to come from a sample from the mud pit with its much greater dilution (DOE 1997, Table H-29). Recall in NEPA20, the sample is taken at the shaker/centrifuge station prior to mixing with other debris.

The primary contributor to the median dose is ^{241}Am in both CH drums and RH shielded containers, but ^{137}Cs and ^{90}Sr are also important in RH shielded containers (Table 13-6). By 400 years, the dose from CH drums has only reduced to 0.01 mSv since not much ^{241}Am has decayed, but dose from RH shielded containers has reduced almost an order of magnitude to 0.0032 mSv.

As a rough corroboration of the point source doses to an individual examining cuttings, cavings, and spallings chips, external areal doses to an individual exposed in a field (planar surface) of soil contaminated at the same concentration as the point source were estimated using GENII (Table 13-5 and Table 13-6). The GENII estimated doses are larger (but by less than a half order of magnitude) except for the mean RH dose at 100 years, which is similar and dominated by ^{137}Cs and ^{90}Sr.

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Table 13-5: Dose to Geologist Examining Cuttings, Cavings, and Spallings 5-cm Spherical Chips from Mean Releases at 100 and 300 Years.

Isotope	Mean Releases 100 y						Mean Releases 300 y					
	CH			RH			CH			RH		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	3.5E-04	91.68%	1.8E-05	2.2E-05	0.57%	1.1E-06	2.6E-04	88.56%	1.3E-05	1.6E-05	29.08%	8.0E-07
^{244}Cm	1.1E-10	0	5.4E-12	4.2E-09	0	2.1E-10	1.8E-12	0	8.8E-14	6.8E-11	0	3.4E-12
^{137}Cs	3.1E-07	0.08%	1.6E-08	1.3E-03	34.60%	6.E-05	3.2E-09	0.	1.6E-10	1.3E-05	24.16%	6.6E-07
^{238}Pu	7.0E-07	0.18%	3.5E-08	1.6E-07	0	7.9E-09	1.8E-07	0.06%	9.0E-09	4.1E-08	0.07%	2.0E-09
^{239}Pu	8.1E-06	2.13%	4.1E-07	6.2E-08	0	3.1E-09	8.1E-06	2.80%	4.0E-07	6.2E-08	0.11%	3.1E-09
^{240}Pu	1.7E-06	0.44%	8.3E-08	4.2E-08	0.	2.1E-09	1.6E-06	0.57%	8.2E-08	4.1E-08	0.07%	2.0E-09
^{241}Pu	4.0E-14	0	2.0E-15	3.9E-15	0.	2.0E-16	3.1E-16	0	1.6E-17	3.0E-19	0	1.5E-20
^{90}Sr	1.1E-06	0.29%	5.5E-08	2.4E-03	62.79%	1.2E-04	9.4E-09	0	4.7E-10	2.0E-05	37.29%	1.0E-06
^{233}U	2.2E-08	0.01%	1.1E-09	7.3E-05	1.91%	3.6E-06	2.2E-08	0.01%	1.1E-09	7.3E-08	0.13%	3.6E-09
^{234}U	2.0E-05	5.20%	9.9E-07	4.3E-06	0.11%	2.1E-07	2.3E-05	8.00%	1.2E-06	5.0E-06	9.08%	2.5E-07
Total	**3.8E-04**		**1.9E-05**	**3.8E-03**		**1.9E-04**	**2.9E-04**		**1.4E-05**	**5.5E-05**		**2.7E-06**
GENII Estimate[b]	**8.0E-04**			**1.3E-03**			**6.0E-04**			**3.5E-05**		

[a]General estimate of mortality of 0.05 Sv^{-1} as suggested by ICRP (ICRP 2007, Section 87).
[b]The GENII estimate is the external dose to an individual exposed while in a large field (planar surface) of contaminated soil, where the contamination is at the same concentration as the 5-cm spherical chips (approximately a point source) of cuttings, cavings, and spallings

Table 13-6: Dose to Geologist Examining Cuttings, Cavings, and Spallings Chips from Median Releases at 100 and 400 Years

Isotope	Median Releases 100 y						Median Releases 400 y					
	CH			RH			CH			RH		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	4.5E-05	98.23%	2.2E-06	1.1E-05	51.03%	5.5E-07	9.4E-6	92.25%	4.7E-07	2.9E-	77.69%	1.4E-07
^{244}Cm	0	0	0	0	0	0	0	0	0.	1.3E-12	0	6.7E-14
^{137}Cs	0	0	0	3.8E-06	17.45%	1.9E-07	0	0	0	4.7E-14	0	2.4E-15
^{238}Pu	4.0E-08	0.09%	2.0E-09	3.0E-09	0.01%	1.5E-10	4.5E-10	0.00%	2.2E-11	1.8E-10	0	9.0E-12
^{239}Pu	8.9E-08	0.19%	4.4E-09	5.4E-08	0.25%	2.7E-09	2.5E-07	2.41%	1.3E-09	2.8E-08	0.77%	1.4E-09
^{240}Pu	6.3E-08	0.14%	3.1E-09	1.7E-08	0.08%	8.7E-10	4.6E-08	0.44%	1.2E-08	4.7E-08	1.28%	2.4E-09
^{241}Pu	5.2E-15	0	2.6E-16	1.8E-15	0	8.9E-17	1.3E-20	0	6.3E-22	1.5E-21	0	7.6E-23
^{90}Sr	0	0	0	6.7E-06	31.00%	3.3E-07	0	0	0	1.2E-15	0	6.0E-17
^{233}U	1.1E-13	0	5.6E-15	2.3E-09	0.01%	1.1E-10	1.2E-10	0	6.2E-12	2.2E-14	0	1.1E-15
^{234}U	6.2E-07	1.35%	3.1E-08	3.6E-08	0.17%	1.8E-09	5.0E-07	4.88%	2.5E-08	7.5E-07	20.26%	3.8E--8
Total	**4.6E-05**		**2.3E-06**	**2.2E-05**		**1.1E-06**	**1.0E-05**		**5.1E-07**	**3.7E-06**		**1.9E-07**
GENII Estimate[b]	**9.8E-05**			**2.8E-05**			**2.2E-05**			**6.7E-06**		

[a]General estimate of mortality of 0.05 Sv^{-1}as suggested by ICRP (ICRP 2007, Section 87).
[b]The GENII estimate is the external dose to an individual exposed while in a large field (planar surface) of contaminated soil, where the contamination is at the same concentration as the 5-cm spherical chips (approximately a point source) of cuttings, cavings, and spallings

13.6 Drilling Debris Pathway

13.6.1 Pathway Description

In the drilling debris pathway, a worker is exposed to radionuclide contamination while around drilling debris. In SEIS-1997, the exposure consisted of external radiation (ground shine) from the debris pit, and incidental ingestion of drilling debris by a drilling crew member over a 21 day, eight hour per day shift. However, significant changes in drilling technology and practices have occurred since SEIS-1990 and SEIS-1997. In 1990 and 1997, drilling practice consisted mostly of two large open mud pits dug into the surface soil. The first mud pit settled the drilling debris and the second pit was a suction reservoir. In 1990, these mud pits would be simply covered up when the drilling was completed; hence, a scenario whereby a family farmed the area 100 years later was conceivable (even though not practicable for the area around WIPP). By 1997, the mud pits were lined, the material deeply buried or possibly moved, and the area reclaimed, but external exposure and ingestion were still conceivable for a drilling crew member.

In 2020, mud pits are not used. The drilling debris is removed by a shaker or centrifuge. The sieved mud is piped to an enclosed mixing tank and then again pumped down into the borehole. The debris is piped to enclosed portable storage tanks. The storage tanks are trucked to a regulated disposal site. The regulated site disposes of drilling debris from possibly thousands of wells. Hence, crew members working around the drilling rig would not be externally exposed to radiation for their entire shift. Furthermore, the opportunity to internally ingest drilling debris does not exist. In the interest of comparing results to SEIS-1997, however, the exposure is shifted to a worker employed at a nearby disposal site where the debris is left uncovered and open to the atmosphere for 21 days where incidental ingestion and external exposure may occur (i.e., these changes in drilling practices make the assumptions of this pathway more conservative).

13.6.2 Radionuclide Activity in Cuttings, Cavings, and Spallings

For the drilling debris pathway, the source of radionuclides is from four sources: cuttings, cavings, spallings, and direct brine release (DBR) to the drilling debris storage tanks. The activity of radionuclides released is the sum of the products of the volume released and the radionuclide concentrations for cuttings, cavings, spallings, and direct brine release (DBR). The volume of cuttings depends upon only the drill bit diameter, which is constant for all intrusions. The volume of cavings varies with each sample vector, because the waste shear strength is uncertain. Volumes of spallings and DBR vary with each scenario, time of intrusion, and sample vector, because spallings and DBR volumes depend strongly on the repository pressure, which in turn varies with scenario, intrusion time, and many sampled material property parameters.

As noted previously in Section 13.5.2, the radionuclide concentration in cuttings and cavings depends upon the waste stream. The mean concentration in cuttings and cavings is the average of all CH-TRU waste streams. The median concentration for each radionuclide is that of the waste stream with median total radionuclide concentration, as described in Section 3.

The radionuclide concentration in spallings varies somewhat with the waste stream, but since spallings incorporates waste from a much larger area of a room, the spallings radionuclide

concentration for dose is assumed to be a volume-averaged CH waste stream concentration, which has a far greater amount of long-lived radionuclides than RH waste streams.[18]

13.6.3 Time of Intrusion

The hypothetical exposure depends upon the timing of the inadvertent drilling intrusion that brings waste to the surface. In WIPP PA calculations, direct brine release (DBR) is the product of DBR volume and mobilized radionuclide concentration in the repository at the time of intrusion, each of which is time dependent. The intrusion time selected is when the DBR release is greatest in the NEPA20 PA analysis, which occurs at t 750 years for Scenario S2-DBR and 1200 years for Scenario S3-DBR (Section 8 and Section 5.2.1).[19]

These two intrusion times are also used to select the spallings volume, which also varies with time. The time that DBR volumes are maximized does not necessarily correspond to when spallings volumes are maximized, but DBR volumes are much greater than spallings volumes.

The mean and median radionuclide concentrations in cuttings, cavings, and spallings from CH waste are summarized in Table 13-7. Because the code EPAUNI does not output values at 750 and 1200 years, the values in Table 13-7 are interpolated from values between 350, 1000, and 3000 years in Table 3-6 and Table 3-7. The doses at 750 years for S2-DBR are somewhat larger than those at 1200 years for S3-DBR and, thus, discussed in the text but values at 1200 years for S3-DBR are tabulated for comparison to demonstrate that the Scenario S2-DBR indeed maximizes dose and is therefore conservative with respect to releases..

[18] The spallings model and waste properties, described in Appendix MASS and Appendix PA of CRA19 (DOE 2019), provide very conservative estimates of spalling release volumes. The spallings model was reviewed in Appendix PEER of CRA04 (DOE 2004).

[19] As described in Appendix MASS of CRA19 (DOE 2019), DBR results assume no closures between some panels in the WIPP repository where actual panels are expected to be emplaced; therefore, the results are still conservative with respect to proposed omission of several panel closures in Panel 9.

Table 13-7: Interpolated Mean and Median Radionuclide Inventory Concentration in Cuttings, Cavings, and Spallings at 750 and 1200 Years when Considering All Waste Streams of CH-TRU (evaluated by CUTTINGS_S)

Isotope	Mean		Median	
	750 y	1200 y	750 y	1200 y
	(Ci/m³)	(Ci/m³)	(Ci/m³)	(Ci/m³)
^{241}Am	6.7E+0	3.6E+0	2.2E-1	5.9E-2
^{244}Cm	2.6E-8	1.6E-19	0	1.4E-52
^{137}Cs	3.4E-7	2.4E-13	5.5E-17	8.0E-17
^{238}Pu	2.8E-1	3.9E-3	2.2E-3	1.2E-3
^{239}Pu	5.1E+1	5.0E+1	1.3E+0	1.1E+0
^{240}Pu	1.2E+1	1.1E+1	3.0E-1	2.5E-1
^{241}Pu	3.3E-7	2.0E-20	1.9E-8	1.1E-21
^{90}Sr	4.1E-7	1.8E-13	0	0
^{233}U	7.1E-4	7.0E-4	3.2E-5	5.7E-4
^{234}U	1.1E-2	1.1E-2	1.6E-3	2.3E-3

13.6.4 Radionuclide Activity in DBR

The radionuclide source activity for a DBR is calculated with PANEL and BRAGFLO-DBR (Table 13-8) (see also Table 8-1). As noted for the geologist pathway, the potential dose from RH-TRU waste is greater at 100 years but quickly decays to less than CH-TRU in 300 years because of the rapid decay of ^{137}Cs and ^{90}Sr. Because the selected intrusion times were set at 750 and 1200 years for the drilling debris pathway, RH-TRU waste with its high ^{137}Cs and ^{90}Sr content is not considered.

Table 13-8: Interpolated Mean and Median Radionuclide Concentration in Direct Brine Release at 750 and 1200 Years

Isotope	Mean of Release Concentration		Median of Release Concentration		Concentration Using Mean Parameters		Concentration Using Median Parameters	
	750 y	1200 y	750 y	1200 y	750 y	1200 y	750 y	1200 y
	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)	(Ci/m^3)
^{241}Am	2.1E+0	1.6+0	3.0E-1	3.4E-1	6.7E-1	6.9E-1	3.6E-1	3.6E-1
^{137}Cs	2.1E-8	7.E-13	2.3E-8	7.9E-13	1.2E-8	7.5E-13	1.1E-8	6.1E-13
^{238}Pu	2.4E-5	7.8E-7	1.7E-6	4.6E-8	6.4E-6	1.9E-7	3.6E-6	1.0E-7
^{239}Pu	4.6E-2	5.2E-2	3.3E-3	3.1E-3	1.2E-2	1.3E-2	7.0E-3	7.2E-3
^{240}Pu	1.1E-2	1.2E-2	7.7E-4	7.0E-4	2.9E-3	2.9E-3	1.7E-3	1.6E-3
^{90}Sr	1.0E-8	2.6E-13	1.1E-8	2.7E-13	5.7E-9	2.6E-13	5.3E-9	2.1E-13
^{233}U	1.2E-4	1.2E-4	6.8E-7	1.0E-6	3.5E-7	3.2E-7	3.3E-7	3.6E-7
^{234}U	1.5E-3	1.5E-3	8.5E-6	1.2E-5	4.3E-6	4.2E-6	4.2E-6	4.2E-6

In NEPA20, the repository pressure has been raised by a previous intrusion through the repository that also intersected a brine pocket below the repository; hence significant DBR releases can occur (Figure 13-1). SEIS-1997 did not consider contaminated brine from direct brine release; but in NEPA20, DBR releases after a previous intrusion contribute a large activity of ^{241}Am: 1.5 orders of magnitude greater activity at selected intrusion times than in cuttings, cavings, and spallings releases. Although the concentration of ^{241}Am in cuttings, cavings, and spallings is 0.5 orders of magnitude greater than in DBR releases (Table 13-7 and Table 13-8), the mean DBR volume of 16.1 m^3 at 750 years is 2 orders of magnitude greater than the combined cuttings, cavings, and spallings volume of 0.110 m^3 at 750 years (Table 13-9) (See also Section 6 and Table 6-5). Similarly, more ^{233}U and ^{234}U comes from DBR than the solid release, with similar amounts of ^{137}Cs and ^{90}Sr in either solid releases or DBR. Radionuclides in the brine are assumed to fully adsorb on the iron remnants from the containers and to be deposited in the storage tanks with other drilling debris.

Table 13-9: Mean and Median Volume of Brine and Waste Solids Released by Intrusion Borehole at 750 Years in Scenario S2-DBR and 1200 Years in Scenario S3-DBR

	Mean Release Volume		Median Release Volume		Volume with Mean Parameters		Volume with Median Parameters	
	750 y	1200 y	750 y	1200 y	750 y	1200 y	750 y	1200 y
Solids								
Cuttings/Cavings (m^3)	0.343	0.343	0.306	0.306	0.301	0.301	0.301	0.301
Spallings (m^3)	0.214	0.038	0	0	0.038	0	0.351	0.183
Total Volume(m^3)	0.557	0.382	0.351	0.316	0.339	0.301	0.652	0.484
Solids Total (m^3)	0.110	0.075	0.069	0.069	0.067	0.059	0.128	0.095
Brine (m^3)	16.1	9.26	15.5	7.48	17.1	15.6	27.5	19.7

13.6.5 Drilling Debris Pathway Parameters

In addition to the radionuclide source, important parameters for the cutting debris pathway are those that determine the concentration of radionuclides in the drilling debris. The contaminant solid concentration of the source is the activity brought to the surface, separated from the drilling fluid brine, and deposited in a 10 m × 10 m disposal area along with other debris from the borehole. Here, the area is set at 100 m^2 as used in SEIS-1997 to increase the intensity of the external dose; in comparison, SEIS-1990 assumed the settling mud pit had an area of 46 m^2 (Lappin et al. 1989, p. 7-7).

The debris volume is the borehole length times (a) the borehole diameter, which is determined by adding the cross-sectional area of the fixed 0.311-m (12¼-inch) diameter borehole and (b) the additional area removed as cavings (Table 13-9). The borehole length has changed since SEIS-1997 because the target strata for oil and gas and the drilling technology has changed since SEIS-1997. Currently, petroleum firms are targeting tight shale strata below the repository horizon but above the deep strata sought in the 1990s. More importantly, the drilling technology includes horizontal drilling. Hence, while the borehole depth has decreased somewhat the total borehole length has greatly increased.

Near WIPP, the Bones Springs Formation at ~3000 m (10,000 ft) is a common target for oil and gas production.[20] The horizontal portion of the well is between 1600 and 4000 m (1 and 2.5 miles). Here, a 4600 m length borehole is used for a total muddy debris volume of between ~350 and 400 m^3, where volume range is because of the different cross-sectional area of the cavings for mean and median results and parameters (Table 13-10). The volume is assumed to be uniformly mixed in storage tanks with the small amount of radionuclides brought to the surface from the repository and then trucked to the disposal site. As noted in Section 13.3.1, Eq (13-7), the biological dose

[20] Information on wells throughout New Mexico, in general, and wells around WIPP, in particular, was obtained from the state database at http;//ocdimage.emnrd.state.nm.us/imaging/WellFileCriteria.aspx

conversion factor is linear and so estimates of dose with other well debris volume can readily be estimated as noted below.

Table 13-10: Parameters of Drilling Debris Pathway

Parameter	Value
Disposal surface area (m^2) (SEIS-1997 assumptions)	100
Period of external exposure (h) (SEIS-1997 assumptions)	168
Period of ingestion exposure (d) (SEIS-1997 assumptions)	21
Ingestion rate (mg/d) (SEIS-1997 assumptions)	100
Volume of borehole debris outside of repository (m^3)	
Mean of releases	399
Median of releases	356
Mean input parameters	350
Median input parameters	350

13.6.6 Drilling Debris Dose

The dose to an employee working around drilling debris is both from the assumed ingestion of 2.1 g of drilling debris (100 mg/d for 21 days) and the external ground shine from a 100 m^2 deposit over 21 days, as summarized above in Section 13.6.5.

The potential mean total dose is 2.8 mSv for intrusion at 750 years in Scenario S2-DBR. At 750 years in Scenario S2-DBR, the external dose is ~1.5 orders of magnitude greater than the ingestion dose (Table 13-11).

The dose with mean parameters does not change much; specifically, the dose is 1.1 mSv for intrusion at 750 years in Scenario S2-DBR (Table 13-12). With a factor of only 2 difference between mean dose and dose results with mean parameters, nonlinearity in the drilling debris analysis is small.

In SEIS-1997, the potential dose with 75th percentile parameters at 300-year intrusion is a factor of 8 larger than NEPA20 at 8.7 mSv (DOE 1997, Table H-27). If the well debris only includes the 3000-m vertical length of the well for a more conservative assumption), then the NEPA20 potential dose is 0.65 mSv at 750 years and still a factor of 5 larger than in NEPA20.

The median potential total dose is 0.41 mSv for intrusion at 750 years in scenario S2-DBR (Table 13-13). The dose with median parameters is 0.90 mSv for intrusion at 750 years in scenario S2-DBR (Table 13-14). In SEIS-1997, the result with median parameters at 400-year intrusion is about a half order of magnitude larger than NEPA20 at 3.6 mSv (DOE 1997, Table H-27).

The important radionuclide contributors to dose for this pathway are ^{241}Am,^{239}Pu, and ^{238}Pu with ^{241}Am by far the most important, which comes primarily from DBR releases. The short-lived ^{90}Sr, ^{137}Cs, and ^{241}Pu have decayed away by 750 years, compared to the external dose for the geologist.

Table 13-11: Mean Dose from to Employee Working around Drilling Debris

Isotope	750 y i Intrusion n Scenario S2-DBR						1200 y Intrusion in Scenario S3-DBR					
	Internal Ingestion			External			Internal Ingestion			External		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	5.6E-5	78.37	7.0E-7	2.7E-3	99.67	1.3E-4	2.4E-5	70.38	3.0E-7	1.2E-3	99.5	5.7E-5
^{137}Cs	4.0E-14		2.0E-15	7.1E-10		3.8E-11	7.4E-19		3.8E-10	1.3E-14		6.9E-16
^{238}Pu	5.6E-8	0.08	8.6E-10	6.6E-8		2.1E-9	5.3E-10		8.2E-12	6.3E-10		2.0E-11
^{239}Pu	1.2E-5	17.45	1.8E-7	6.0E-6	0.22	2.1E-7	8.3E-6	24.10	1.2E-7	4.1E-6	0.34	1.4E-7
^{240}Pu	2.9E-6	4.09	4.2E-8	3.0E-6	0.11	9.4E-8	1.9E-6	5.50	2.7E-8	2.0E-6	0.16	6.1E-8
^{90}Sr	4.4E-14		2.6E-11	1.1E-12		1.8E-14	5.2E-19		3.0E-20	1.3E-17		2.1E-19
^{233}U	7.9E-10			4.0E-9		1.7E-10	4.6E-10	0.02	1.5E-11	2.3E-9		96E-11
^{234}U	9.6E-9	0.01		4.9E-8		1.7E-9	5.6E-9		1.9E-10	2.8E-8		9.7E-10
Total	**7.1E-5**		**9.2E-7**	**2.8E-3**		**1.3E-4**	**3.4E-5**		**4.5E-7**	**1.2E-3**		**5.7E-5**

[a]The probability of cancer fatality is from Federal Guidance Report 13 as programmed in GENII, which is recommended for risk assessments used in environmental impact statements.

Table 13-12: Dose to Employee Working around Drilling Debris using Mean Parameters

Isotope	750 y Intrusion in Scenario S2-DBR						1200 y Intrusion in Scenario S3-DBR					
	Internal Ingestion			External			Internal Ingestion			External 1		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	2.2E-5	68.58	2.7E-7	1.1E-3	99.45	5.1E-5	2.0E-5	69.47	2.5E-7	9.8E-4	99.48	4.7E-5
^{137}Cs	2.8E-14		1.4E-15	4.9E-10		2.6E-11	1.4E-18		7.2E-20	2.5E-14		1.3E-15
^{238}Pu	3.9E-8	0.12	6.0E-10	4.6E-8		1.4E-9	4.7E-10		7.2E-12	5.6E-10		1.7E-11
^{239}Pu	8.0E-6	25.32	1.2E-7	4.0E-6	0.37	1.4E-7	4.1E-6	24.88	1.0E-7	3.5E-6	0.35	1.2E-7
^{240}Pu	1.9E-6	5.98	2.7E-8	2.0E-6	0.18	6.1E-8	1.6E-6	5.65	2.3E-8	1.7E-6	0.17	5.2E-8
^{90}Sr	3.1E-14		1.8E-15	7.9E-13		1.2E-14	9.8E-19		5.8E-20	2.5E-17		4.0E-19
^{233}U	2.4E-11		8.0E-13	1.2E-10		5.1E-12	2.1E-11		7.0E-13	1.1E-10		4.5E-12
^{234}U	3.4E-10		1.2E-11	1.7E-9		6.0E-11	3.1E-10		1.0E-11	1.6E-9		5.4E-11
Total	**3.2E-5**		**4.2E-7**	**1.1E-3**		**5.1E-5**	**2.8E-5**		**3.8E-7**	**9.8E-4**		**4.7E-6**

[a]The probability of cancer fatality is from Federal Guidance Report 13 as programmed in GENII, which is recommended for risk assessments used in environmental impact statements (Eckerman et al. 1999).

Table 13-13: Median Dose to Employee Working around Drilling Debris

Isotope	750 y Intrusion in Scenario S2-DBR						1200 y Intrusion in Scenario S3-DBR					
	Internal Ingestion			External			Internal Ingestion			External		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	8.4E-6	95.60	1.0E-7	4.1E-4	99.94	2.0E-5	4.5E-6	94.72	5.7E-8	2.2E-4	99.93	1.1E-5
^{137}Cs	4.2E-14		2.1E-15	7.2E-10		3.9E-11	7.0E-19		3.6E-20	1.2E14		6.6E-16
^{238}Pu	3.6E-10		5.5E-12	4.2E-10		1.3E-11	1.5E-1		2.4E-12	1.8E-10		5.7E-12
^{239}Pu	3.1E-7	3.58	4.5E-9	1.5E-7	0.04	5.4E-9	2.1E-7	4.33	3.0E-9	1.0E-7	0.05	3.6E-9
^{240}Pu	7.1E-8	0.81	1.0E-9	7.3E-8	0.02	2.3E-9	4.5E-8	0.95	6.6E-10	4.7E-8	0.02	1.5E-9
^{90}Sr	4.0E-14		2.3E-15	1.0E-12		1.6E-14	4.9E-19		2.8E-10	1.2E-17		2.0E-19
^{233}U	5.7E-12		1.9E-13	2.9E-11		1.2E-12	1.9E-11		6.3E-13	9.6E-11		4.0E-12
^{234}U	1.0E-10		3.5E-12	5.3E-10		1.8E-11	1.0E-10		3.4E-12	5.2E-11		1.8E-11
Total	**8.7E-6**		**1.1E-7**	**4.1E-4**		**2.0E-5**	**4.8E-6**		**6.0E-8**	**2.2E-4**		**1.1E-5**

[a]The probability of cancer fatality is from Federal Guidance Report 13 as programmed in GENII, which is recommended for risk assessments used in environmental impact statements (Eckerman et al. 1999).

Table 13-14: Dose to Employee Working around Cutting Debris using Median Parameter Input

Isotope	750 y Intrusion in Scenario S2-DBR						1200 y Intrusion in Scenario S3-DBR					
	Internal Ingestion			External			Internal Ingestion			External		
	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]	Dose (Sv/y)	Percent	Cancer Fatality[a]
^{241}Am	1.8E-5	94.69	2.2E-7	8.8E-4	99.93	4.2E-5	1.3E-5	94.98	1.6E-7	6.3E-4	99.94	3.0E-5
^{137}Cs	3.7E-14		1.9E-15	6.5E-10		3.5E-11	1.4E-18		7.3E-20	2.5E-14		1.4E-15
^{238}Pu	7.8E-10		1.2E-11	9.2E-10		2.9E-11	2.4E-10		3.7E-12	2.9E-10		8.9E-12
^{239}Pu	8.1E-7	4.32	1.2E-8	4.0E-7	0.05	1.4E-8	5.6E-7	4.10	8.1E-9	2.7E-7	0.04	9.6E-9
^{240}Pu	1.9E-7	0.99	2.7E-9	1.9E-7	0.02	6.0E-9	1.2E-7	0.91	1.8E-9	1.3E-7	0.02	4.0E-9
^{90}Sr	3.5E-14		2.1E-15	9.1E-13		1.4E-14	1.0E-18		5.9E-20	2.6E-17		4.1E-19
^{233}U	6.0E-12		2.0E-13	3.0E-11		1.3E-12	2.8E-11		9.2E-13	1.4E-10		5.9E-12
^{234}U	1.4E-10		4.7E-12	7.1E-10		2.4E-11	1.3E-10		4.4E-12	6.7E-10		2.3E-11
Total	**1.9E-5**		**2.4E-7**	**8.8E-4**		**4.2E-8**	**1.4E-5**		**1.7E-7**	**6.3E-4**		**3.0E-5**

[a]The probability of cancer fatality is from Federal Guidance Report 13 as programmed in GENII, which is recommended for risk assessments used in environmental impact statements.

13.7 Rancher Pathway

13.7.1 Pathway Description

In this pathway, inadvertent human intrusion results in radionuclide transport from the repository through the borehole to the overlying Culebra formation, and then through the Culebra to the WIPP land withdrawal boundary (LWB) At the LWB, a hypothetical rancher withdraws contaminated water to a stock pond for cattle, then consumes the cattle. The contamination derives from a repository intrusion at 100 years to maximize the radionuclide transport to the LWB.

13.7.2 Rancher Pathway Parameters

The simple hypothetical rancher pathway uses two key parameters: cattle drinking rate (26 L/d), and rancher consumption rate (Table 13-15). The rancher beef consumption rate of 42 kg/y for one year is the same exposure as used for SEIS-1997. The rancher consumption rate in SEIS-1990 was set at either 31 kg/y or 75 kg/y (Lappin et al. 1989, p. 7-68).

Table 13-15: Parameters for Rancher Pathway

Parameter	Value
Rancher beef consumption rate (kg/y) (SEIS-1997 assumption)	42
Consumption holdup (d)	34
Cattle drinking rate (L/d) (SEIS-1997 assumptions)	26

13.7.3 Radionuclide Activity

Radionuclide releases at the LWB are derived from the NEPA20 PA results as described in Section 11. Two sets of results are considered: (1) one set uses the mean and median cumulative radionuclide flux from the NEPA20 PA, and (2) another set uses mean and median input parameters for the MODFLOW and SECOTP2D codes, as determined by travel time of a conservative tracer to the LWB using the particle tracking code DTRKMF.

Only the mean of radionuclide mass released is found to be significant (Table 13-16 or Table 11-2). The median of the radionuclide mass release is very small (Table 11-2). Similar to the releases in SEIS-1997, the radionuclide mass released to the LWB when mean parameters values are used in the analysis are practically zero (Table 13-16). A similar situation occurs for median parameter values but is not shown.

As noted in Section 13.3.1, the concentration is not directly calculated in PA. Rather, the mass crossing the LWB is evaluated, since the cumulative mass is the performance metric for the EPA Standard, 40 CFR 191. To avoid a major change in the PA analysis for the dose calculations, the concentration was derived from the peak mass release rate and a reasonable but conservative well withdrawal rate. As fully explained in Section 11, the peak annual release rate of each radionuclide that crosses the LWB over the 10,000-yr regulatory period is determined from the differentiated

cumulative releases and the maximum rate for each radionuclide is selected.[21] The withdrawal rate is set at 3500 m^3/y, which is reasonable for supplying drinking water for 100 head of cattle in a hot, arid, salty environment and ~4 times the cattle water consumption assumed here and in SEIS-1997.[22] The well drawdown from this withdrawal rate could reasonably capture the entire radionuclide mass that crosses the LWB, where the contaminant plume width spans ~0.5 km for the full mining scenario (but not necessarily capture the entire ~ 2 km plume width for the partial mining scenario) (Kuhlman, 2010, Figure 3-15).

Table 13-16: Radionuclide Mass Released and Concentration at the Land Withdrawal Boundary from 100-y Intrusion (Mean of Releases based on Table 11-2)

Isotope	Maximum Isotope Release Rate at LWB (Ci/y)	Time of Maximum Release Rate (y)	Isotope Concentration at LWB (Ci/m^3)
Mean of Releases	$^{Max}\mathcal{M}_r(t;\mathbf{p})$		$\frac{1}{Q^{well}}{}^{Max}\mathcal{M}_r(t;\mathbf{p})$
^{241}Am	3.56E-10	1,450	1.02E-13
^{241}Pu	1.12E-11	1,450	3.20E-15
^{239}Pu	1.08E-06	10,000	3.10E-10
^{240}Pu	1.25E-07	10,000	3.58E-11
^{242}Pu	1.33E-09	10,000	3.80E-13
^{234}U	7.53E-05	9,500	2.15E-08
^{233}U	7.32E-06	9,500	2.09E-09
^{230}Th	1.08E-10	10,000	3.10E-14
^{229}Th	6.66E-11	10,000	1.90E-14

[21] Traditionally in dose calculations, the maximum concentration in the contaminant plume over the regulatory period is used (e.g., assessing individual dose in 40 CFR 191).As a surrogate for evaluating the full contaminant plume in this analysis, the release rate is calculated and the maximum selected.

[22] The withdrawn amount could increase to 3.7×10^6 m^3/y if the contaminated water was used to grow alfalfa to feed the cattle; however, the residue contamination in the alfalfa would need to be included in the dose calculation. GENII can perform this calculation but it was not included here to match the assumptions of SEIS-1997. The effect of diluting radionuclides by increasing withdrawal volume by two orders of magnitude is greater than the possibly 1.3 order of magnitude increase in dose.

Table 13-17: Radionuclide Mass Released and Concentration at the Land Withdrawal Boundary Intrusion at 100 Years (Mean Parameters)

Isotope	Maximum Isotope Release Rate at LWB (Ci/y)	Time of Maximum Release Rate (y)	Isotope concentration at LWB (Ci/m^3)
Mean Parameters	$^{Max}\mathcal{M}_r(t;\mathbf{p})$		$\frac{1}{Q^{well}}{}^{Max}\mathcal{M}_r(t;\mathbf{p})$
^{241}Am	2.19E-41	4,250	6.26E-45
^{241}Pu	6.80E-43	4,250	1.94E-46
^{239}Pu	2.68E-38	10,00	7.65E-42
^{240}Pu	3.09E-39	10,00	8.83E-43
^{242}Pu	3.29E-41	10,000	9.39E-45
^{234}U	0		0
^{233}U	0		0
^{230}Th	1.24E-44	10,000	3.53E-48
^{229}Th	7.60E-45	10,000	2.17E-48

13.7.4 Rancher Pathway Dose

The potential dose from the mean of radionuclide releases is the largest at 2.8×10^{-8} Sv/y or 9.2×10^{-10} risk/y (Table 13-18). As readily apparent from Table 13-16, the dose from the mean input parameters are zero or practically so. Similarly, the median of release is practically zero as readily apparent from Table 11-2. By comparison, the dose with median parameters and 75th percentile parameters were also practically zero in SEIS-1997 (DOE 1997, p. H-67): 1.4×10^{-26} Sv/y (or 7×10^{-28} risk/y) for median parameters.

The large difference between the dose of mean releases and doses with mean parameters is a measure of the nonlinearity in the pathway release through the Culebra to the rancher (32 orders of magnitude between concentration of ^{239}Pu in Table 13-16 and Table 13-17).

Uranium isotopes are the most important contributors to the dose from mean releases. For the mean of radionuclide releases, for example, ^{234}U represents 89.8% of the transport and contributes 90.65% to the total dose of 2.8×10^{-8} Sv/y (Table 13-18). The ^{233}U represents 9.1% of the transport and contributes 8.74% to the total dose. Only ^{234}U is actually transported in the model of the Culebra. The concentration of ^{233}U is estimated by the isotope activity fraction at the time of the maximum release rate of uranium (9500 y) (Table 13-16).

Conceivably, the fraction of other isotopes of uranium (e.g., ^{235}U and ^{238}U) could be handled similar to ^{233}U. They are not, however, since the EPA Standard only monitors ^{234}U and ^{233}U. In

the situation here, the total dose is still practically the same at 2.8×10^{-8} Sv/y if the fractional contribution of ^{235}U and ^{238}U is also included because ^{235}U and ^{238}U represent such a small portion of the activity (1.5 orders of magnitude less dose than ^{234}U).

Table 13-18: Mean Dose to Rancher Consuming Own Cattle that Drink from Contaminated Stock Pond

Isotope	Mean of Releases		
	Dose (Sv)	Percent	Cancer Fatality[a]
^{241}Am	6.44.6E-14		8.1E-16
^{239}Pu	6.0E-11	0.22	8.8E-13
^{240}Pu	7.0E-12	0.03	21.0E-13
^{241}Pu	1.2E-17		1.2E-19
^{242}Pu	7.0E-14		1.0E-152
^{225}Ra	4.4E-14		1.3E-15
^{229}Th	3.4E-13		3.9E -15
^{230}Th	2.1E-14		2.1E-16
^{233}U	2.5E-9	9.10	8.2E-11
^{234}U	2.5E-8	90.65	8.3E-10
Total	**2.8E-8**		**9.2E-10**

[a]The probability of cancer fatality is from Federal Guidance Report 13 as programmed in GENII, which is recommended for risk assessments used in environmental impact statements (Eckerman et al. 1999).

13.7.5 Inventory Impact Assessment: 2050 vs. 2072 Facility Closure Date

The inventory data used in the NEPA20 analysis is based on an assumed WIPP closure date of 2050. An alternative closure date of 2072 has been considered and an updated inventory has been provided for the purposes of comparison here (Van Soest 2020). The primary difference between the 2050 inventory and 2072 inventory is that the radionuclides in each waste stream have been subjected to an additional 22 years of radioactive decay and ingrowth. As a result, the curie counts for each radionuclide are different between the two inventories. However, the assumed waste stream volumes and nonradiological inventories are assumed to be identical between the two inventories.[23] This section considers the potential impacts to the NEPA20 results if a closure date of 2072 were assumed.

The initial activities of radionuclides key to PA calculations for the NEPA20 analysis based on a 2050 closure date are tabulated in Kicker (2020) and repeated here in Table 13-19 along with initial activities based on a 2072 closure date. Activities at 10,000 years post-closure are compared in

[23] Nonradiological inventories include organic ligand inventories. Organic ligand inventories are used to calculate radionuclide solubility in brine—because the inventory is assumed to be independent of closure date, there is no expected impact to solubilized releases.

Table 13-20 for both assumed closure dates. Lower doses would be expected due to the overall lower activity.

Additionally, the WUF is recalculated based on a 2072 closure date inventory; results are shown in Table 13-21. The recalculated WUF has little potential impact on releases in EPA units, as it is a normalizing factor that, when applied to the initial activity, results in approximately 10,000 EPA Units of initial inventory regardless of the value of the WUF.

Table 13-19: Activities in Curies for Principal PA Radionuclides at Closure Dates of 2050 and 2072

Radionuclide	CH			RH		
	2050	2072	Percent Difference	2050	2072	Percent Difference
Am-241	3.21E+06	3.16E+06	-1.45%	1.28E+04	1.27E+04	-0.27%
Cs-137	4.91E+02	2.95E+02	-39.85%	1.34E+05	8.05E+04	-39.85%
Pu-238	1.96E+06	1.65E+06	-15.96%	2.87E+04	2.41E+04	-15.96%
Pu-239	8.77E+06	8.77E+06	-0.06%	4.35E+03	4.35E+03	-0.06%
Pu-240	2.19E+06	2.18E+06	-0.23%	3.49E+03	3.51E+03	0.62%
Sr-90	7.49E+02	4.36E+02	-41.83%	1.06E+05	6.14E+04	-41.83%
U-233	1.19E+02	1.19E+02	0.00%	2.55E+01	2.55E+01	-0.01%
U-234	1.09E+03	1.20E+03	10.21%	1.50E+01	1.67E+01	10.86%

Table 13-20: Activities for Principal PA Radionuclides 10,000 after Closure Dates of 2050 and 2072

Radionuclide	CH			RH		
	2050	2072	Percent Difference	2050	2072	Percent Difference
Am-241	4.53E+00	4.51E+00	-0.44%	5.35E+00	5.34E+00	-0.18%
Cs-137	--	--	--	--	--	--
Pu-238	1.22E-20	1.10E-20	-10.25%	2.62E-21	2.35E-21	-10.25%
Pu-239	6.58E+06	6.58E+06	-0.06%	3.33E+03	3.33E+03	-0.06%
Pu-240	7.61E+05	7.59E+05	-0.23%	1.23E+03	1.23E+03	-0.23%
Sr-90	--	--	--	--	--	--
U-233	1.44E+02	1.44E+02	0.04%	2.49E+01	2.49E+01	-0.01%
U-234	1.74E+03	1.74E+03	-0.01%	2.47E+01	2.47E+01	-0.01%

Table 13-21: Comparison of the Waste Unit Factor for Closure Dates of 2050 and 2072

Radionuclide	2050 Closure		2072 Closure	
	Activity (Ci)	Fraction	Activity (Ci)	Fraction
Am-241	3.22E+06	19.897%	3.17E+06	20.074%
Am-242m	1.51E+01	0.000%	1.36E+01	0.000%
Am-243	4.83E+02	0.003%	4.82E+02	0.003%
Cf-249	8.88E+01	0.001%	8.50E+01	0.001%
Cf-251	1.79E+01	0.000%	1.76E+01	0.000%
Cm-243	1.60E+01	0.000%	9.35E+00	0.000%
Cm-245	1.76E+01	0.000%	1.78E+01	0.000%
Cm-246	6.66E+02	0.004%	6.64E+02	0.004%
Cm-247	1.45E+00	0.000%	1.45E+00	0.000%
Cm-248	3.76E+00	0.000%	3.76E+00	0.000%
Cm-250	2.28E-06	0.000%	2.28E-06	0.000%
Np-237	8.90E+01	0.001%	1.12E+02	0.001%
Pu-238	1.99E+06	12.283%	1.67E+06	10.567%
Pu-239	8.78E+06	54.256%	8.77E+06	55.505%
Pu-240	2.19E+06	13.552%	2.19E+06	13.841%
Pu-242	5.12E+02	0.003%	5.12E+02	0.003%
Pu-244	9.54E-02	0.000%	9.54E-02	0.000%
Total	1.62E+07	100.000%	1.58E+07	100.000%
WUF	16.18		15.80	

The changes in initial inventory are due to radioactive decay and ingrowth over the 22 years between 2050 and 2072. In general, those radionuclides with shorter half-lives (e.g., Cs-137, Pu-238, and Sr-90 have greater relative changes than those with longer half-lives (e.g., Pu-239 and U-233) (Table 13-19). One exception to this general observation of the differences between the two inventories is that U-234, despite a relatively long half-life, *increases* in inventory over the 22 years. This increase in inventory is due to U-234 being a by-product of Pu-238 decay. Of the key radionuclides tracked in NEPA20 analysis, U-234 has a relatively small inventory. As a result, the overall activity of all radionuclides in the WIPP inventory is smaller for the 2072 closure date inventory compared to the 2050 closure date inventory at all times (Table 13-22). This is also reflected in the smaller WUF value (Table 13-21).

Table 13-22: Comparison of Overall Inventories for Closure Dates of 2050 and 2072

Years Past Closure	CH + RH Inventory (Ci)		Difference (Ci)	Percent Difference
	2050 Closure	2072 Closure		
0	1.98E+07	1.72E+07	-2.61E+06	-13.2
100	1.47E+07	1.44E+07	-2.87E+05	-1.9
350	1.28E+07	1.27E+07	-9.61E+04	-0.7
1000	1.12E+07	1.11E+07	-3.33E+04	-0.3
5000	8.90E+06	8.89E+06	-7.86E+03	-0.1
10000	7.35E+06	7.35E+06	-5.94E+03	-0.1

The largest differences in inventory are at early times prior to 100 years post-closure. By 350 years post-closure, there is little difference (less than 1%) between the inventories. Thus, there is little impact expected to the results of the NEPA20 analysis due to the assumption of a 2072 closure date compared to a 2050 closure date and any impact is expected to decrease the activity of calculated releases.

13.8 Summary

Potential dose is calculated for three pathways with inputs taken from the full range of NEPA20 results. Mean dose for each hypothetical release pathway is summarized in Table 13-23. When comparing the results of dose calculations from the NEPA20 analysis and SEIS-1997, the differences in assumptions for each pathway, as well as calculation methodology, should be kept in mind. While the names of the pathways are the same between the two analyses, the assumptions have changed somewhat for the NEPA20 analysis as discussed throughout Section 13. Dose calculations in SEIS-1997 use the results of a single PA realization that used median parameter values. For the NEPA20 analysis, the dose calculations were based on the mean results from 300 PA realizations using sampled input values. The results presented in Table 13-23 are the NEPA20 doses calculated for each hypothetical release pathway.

However, solely for the sake of comparing identical dose calculation methodologies (with the understanding that some of the assumptions for each release pathway have changed between analyses), dose calculations have been performed as part of the NEPA20 analysis that were based on the results of a single PA realization that used median parameter values. Table 13-24 summarizes the potential dose with median parameters for each pathway evaluated in NEPA20 to reasonably compare to potential dose evaluated in SEIS-1997, which was also calculated using median parameters (the results presented in Table 13-23 are also presented in Table 13-24 for comparison of the two NEPA20 dose calculations). The potential dose calculated using median parameters for the hypothetical rancher pathway is practically zero in both NEPA20 and SEIS-1997. The different sampling location for drilling debris (i.e., the level of dilution) drives the difference in potential dose for the hypothetical geologist pathway, which shows a greater potential dose in NEPA20. For SEIS-1997, the sample is taken in the mud pit which introduces more dilution in the radionuclide content. For NEPA20, the sample is taken at the drill head before any opportunity to mix with other drilling debris in the storage tank. The potential dose to a worker

disposing of drilling debris in NEPA20 is somewhat greater than the potential dose to a drilling operator working around a drilling mud pit in SEIS-1997. The difference in this latter pathway occurs because of the conservative inclusion in the NEPA20 analysis of direct brine release with its higher ^{241}Am content and the different hydrocarbon target horizon.

Table 13-23: Summary of Dose Results for the NEPA20 Analysis

Release Pathway	PA Results		Mean Dose			
	Intrusion Time (yr)	Table	Dose Source	Value (Sv/y)	Latent Cancer Fatality (y^{-1})	Table
Geologist	100	Table 3-6	External (only source)	3.8E-3	1.9E-4	Table 13-5
Drilling Debris Disposal	750	Table 3-6 Table 8-1	External Ingestion	2.8E-3 7.1E-5	1.3E-4 9.2E-7	Table 13-11
Rancher	100	Table 11-2	Ingestion (only Source)	2.8E-8	9.2E-10	Table 13-18

Table 13-24: Comparison of the Two NEPA20 Dose Calculations with SEIS-1997 Dose Calculations

Release Pathway[a]	Dose Source	NEPA20 Mean Outputs[b]			NEPA20 Median Parameters[c]			SEIS-1997 Median Parameters[d]		
		Intr. Time (yr)	Dose Value (Sv/y)	Table	Intr. Time (yr)	Dose Value (Sv/y)	Table	Intr. Time (yr)	Dose Value (Sv/y)	Table
Geologist	External	100	3.8E-3	Table 13-5	400	1.0E-5	13-6	400	5.7E-8	H-29
Drilling Debris Disposal	External Ingestion	750	2.8E-3 7.1E-5	Table 13-11	750	8.8E-4 1.9E-5	13-14	400	1.0E-4 3.5E-3	H-27
Rancher	Ingestion	100	2.8E-8	Table 13-18	100	~0	-	100	~0	-

[a]-Some assumptions for the hypothetical release pathways differ between the SEIS-1997 and NEPA20 analyses. See text throughout Section 13 for details.
[b]-Dose calculations based on inputs from the mean NEPA20 PA results across 300 vectors.
[c]-Dose calculations based on inputs from the results of a single vector from the NEPA20 PA using median input parameter values.
[d]-Dose calculations based on inputs from the results of a single vector from the SEIS-1997 analysis using median input parameter values.

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14 Summary

The NEPA20 analysis was carried out in two stages: first, PA calculations quantify the potential releases to the accessible environment over a 10,000-year post-closure period. Second, dose was evaluated for three hypothetical exposure pathways using the conservative radionuclide concentrations assumed to be released to the accessible environment.

The NEPA20 PA calculations are based on the PA calculations performed for the CRA19 submitted by the DOE to the EPA. The CRA19 baseline calculations included the hypothetical scenario (based on the Certification Criteria in Title 40 CFR Part 194.41) of a lack of DOE institutional control over the WIPP facility starting from 100 years post-closure and continuing throughout the 10,000-year regulatory period; under this hypothetical scenario, inadvertent human intrusion is assumed to potentially occur over 9,900 years. As a result, the CRA19 calculations were conservative in nature, meaning that the calculated releases are greater than could be expected if DOE retains active institutional controls for much longer than 100 years during the 10,000 year regulatory period.

The CRA19 calculations also incorporates various sources of uncertainty and in cases where handling the uncertainty required making choices among potential assumptions, modeling assumptions were chosen such that releases exceed expectations (DOE 2019, Appendix MASS). As a result, the CRA19 calculations are conservative in nature, meaning that the calculated releases are on average greater than could be expected if there were no uncertainty in them. The NEPA20 analysis has the CRA19 conservative assumptions as its basis; however, additional modeling assumptions are made for the NEPA20 analysis and in each case conservative assumptions are made. As a result, the NEPA20 calculations are also conservative in nature, meaning that the calculated releases to the accessible environment and doses to hypothetical members of the public are higher than could be expected.

WIPP PA modeling limitations make explicit modeling of the additional 9 panels computationally prohibitive, but the explicit modeling of each panel in the WIPP design has not been a part of past WIPP PA compliance calculations. Instead, three representative waste regions are used in the Salado flow (i.e., BRAGFLO) model when a 10-panel design has been modeled. Instead of increasing the volume of the repository in the Salado flow grid, the additional 9 panels are accounted for by assuming that they behave like a panel in the 10-panel grid and radiological and nonradiological inventory parameters have been scaled appropriately to represent the homogenous spreading of the entire inventory across all 19 waste panels. Because releases in the 10-panel representation are themselves conservative (Zeitler et al. 2017), application of these higher representative releases to the additional 9 panels will result in higher releases than if those additional 9 panels were modeled explicitly.

The NEPA20 analysis quantifies the expected dose exposure via three exposure pathways by using the results of the PA calculations described above that consider: 1) a WIPP repository consisting of 19 waste panels; and 2) a waste inventory that includes a waste stream with ~42.2 MT of surplus Pu TRU waste from the National Nuclear Security Administration (NNSA) Surplus Plutonium Disposition (SPD) project at the Savannah River Site (SRS). The three exposure pathways considered in this analysis are: 1) exposure of hypothetical drill rig workers to drilling debris around a mud pit for 21 days at the surface; 2) exposure of a hypothetical geologist examining drill cuttings for 1 hour at the surface; and (3) exposure of a hypothetical rancher using water from well

at the land withdrawal boundary (LWB). The drill rig workers, geologist, and rancher are not real people, but are assumed to be members of the public in hypothetical future scenarios. For the dose calculations, a single intrusion is considered; the intrusion time and location and repository conditions are conservatively selected when the radionuclide releases are greatest. The results of dose calculations are summarized in Table 14-1.

The analysis is not in support of a planned change request (PCR) or planned change notice (PCN) to be submitted by the DOE to the EPA and was not performed as a compliance calculation. Instead, the planned use of the analysis is as input into a National Environmental Policy Act (NEPA) analysis.

Table 14-1: Summary of Dose Calculation Results for the NEPA20 Analysis

Release Pathway	PA Results		Mean Dose			
	Intrusion Time (yr)	Table	Table	Primary Dose Source	Value (Sv/y)	Latent Cancer Fatality (y^{-1})
Geologist	100	Table 3-6	Table 13-5	External (only source)	3.8E-3	1.9E-4
Drilling Debris Disposal	750	Table 3-6 Table 8-1	Table 13-11	External Ingestion	2.8E-3 7.1E-5	1.3E-4 9.2E-7
Rancher	100	Table 11-2	Table 13-18	Ingestion (only Source)	2.8E-8	9.22E-10

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16 Run Control

This section provides the following details for the NEPA20 calculations:

- A description of the hardware platform and operating system used to perform the calculations (Section 16.1).
- A listing of the codes and versions used to perform the calculations (Section 16.2).
- A listing of the scripts used to run each calculation (Sections 16.3-16.10).
- A listing of the input and output files for each calculation (Sections 16.3-16.10).
- A listing of the library where each file is stored (Sections 16.3-16.10).
- File naming conventions (Sections 16.3-16.10).

16.1 Hardware Platform and Operating System

NEPA20 was executed on the Solaris Cluster (Oracle/SUN X6270 m2, Oracle/SUN X4-2B, and Dell PowerEdge R820) with SunOS 5.11 11.3 i86pc i386 i86pc. Calculations were run from the /home/run_mast/GD area on the santana node and results were later moved to /nfs/data/CVSLIB/WIPP_ANALYSES/NEPA20.

16.2 Code Versions used in NEPA20 Calculations

The NEPA20 planning document specified a list of codes with versions that were planned to be used in the NEPA20 analysis.

The following code versions were used in NEPA20 calculations:[24] ALGEBRACDB v2.36, BRAGFLO v7.00, CCDFGF v7.04, CCDFVECTORSTATS v1.01, CUTTINGS_S v6.03, DRSPALL v1.22, EPAUNI v1.19, GENII v2.10, GENMESH v6.10, ICSET v2.23, LHS v2.44, MATSET v9.24, MERGESPALL v1.01, NUTS v2.07, PANEL v5.00, POSTBRAG v4.02, POSTLHS v4.11, POSTSECOTP2D v1.05, PREBRAG v9.00, PRECCDFGF v2.01, PRELHS v2.44, PRESECOTP2D v1.23, RELATE v1.45, SCREEN_NUTS v1.02, SECOTP2D v1.43, SUMMARIZE v3.02, STEPWISE v2.22.

Additionally, Python and Microsoft Excel were used as post-processing tools for the intrusion time calculations (Sections 8 and 11). Associated files are located on the santana system at /nfs/data/CVSLIB/WIPP_EXTERNAL/NEPA20/Files/NEPA20_PostProcessing.zip.

[24] DRSPALL v1.22 and MERGESPALL v1.01 were not rerun for NEPA20. Instead, the DRSPALL v. 1.22 and MERGESPALL v1.01 output results from a previous run (Kirchner et al. 2015) were used as input to the NEPA20 calculations. Similarly, PRESECOTP2D v1.23, POSTSECOTP2D v1.05, and SECOTP2D v1.43 were not rerun for NEPA20. Instead, the PRESECOTP2D v1.23 and SECOTP2D v1.43 output results from a previous run (Kirchner et al. 2014) were used as input to the NEPA20 calculations. In all cases, the changed inputs to the NEPA20 analysis would not have changed the results of running these codes.

16.3 LHS

Table 16-1: LHS Run Script Files

File	Repository	Comment
RunControl/LHS.py	$REP1/NEPA20/LHS	Python run control script
RunControl/LHSlib.py	$REP1/NEPA20/LHS	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/LHS	Run control module
RunControl/Run.py	$REP1/NEPA20/LHS	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-2: LHS Input File

File	Repository	Comment
Input/lhs1_NEPA20_r*i*_con.inp	$REP1/NEPA20/PRELHS	Input file

Where:

i is 1-3

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-3: LHS CVS Repositories

CVS Repositories
$CODE/LHS
$CODE/PRELHS
$REP1/NEPA20/LHS
$REP1/NEPA20/PRELHS

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-4: LHS Log Files

File	Repository	Comment
RunControl/LHS.log	$REP1/NEPA20/LHS	Log file
RunControl/LHS.rtf	$REP1/NEPA20/LHS	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-5: LHS Output Files

File	Repository	Comment
Output/lhs1_NEPA20_r*i*_con.dbg	$REP1/NEPA20/PRELHS	Debug file
Output/lhs1_NEPA20_r*i*_con.trn	$REP1/NEPA20/PRELHS	Transfer file
Output/lhs2_NEPA20_r*i*_con.dbg	$REP1/NEPA20/LHS	Debug file
Output/lhs2_NEPA20_r*i*_con.trn	$REP1/NEPA20/LHS	Transfer file

Where:

i is 1-3

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-6: LHS Executable Files

File	Repository	Comment
Build/Solaris/lhs (Ver:2.44)	$CODE/LHS	Code to sample uncertain parameters
Build/Solaris/prelhs (Ver:2.44)	$CODE/PRELHS	Pre-processes data for lhs

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.4 EPAUNI

Table 16-7: EPAUNI Run Script Files

File	Repository	Comment
RunControl/EPAUNI.py	$REP1/NEPA20/EPAUNI	Python run control script
RunControl/EPAUNIlib.py	$REP1/NEPA20/EPAUNI	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/EPAUNI	Run control module
RunControl/Run.py	$REP1/NEPA20/EPAUNI	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-8: EPAUNI Input Files

File	Repository	Comment
Input/epu_NEPA20_ch.inp	$REP1/NEPA20/EPAUNI	Input file
Input/epu_NEPA20_ch_misc.inp	$REP1/NEPA20/EPAUNI	Input file
Input/epu_NEPA20_rh.inp	$REP1/NEPA20/EPAUNI	Input file
Input/epu_NEPA20_rh_misc.inp	$REP1/NEPA20/EPAUNI	Input file

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-9: EPAUNI CVS Repositories

CVS Repositories
$CODE/EPAUNI
$REP1/NEPA20/EPAUNI

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-10: EPAUNI Log Files

File	Repository	Comment
RunControl/EPAUNI.log	$REP1/NEPA20/EPAUNI	Log file
RunControl/EPAUNI.rtf	$REP1/NEPA20/EPAUNI	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-11: EPAUNI Output Files

File	Repository	Comment
Output/epu_NEPA20_ch.dat	$REP1/NEPA20/EPAUNI	Results file
Output/epu_NEPA20_ch.dia	$REP1/NEPA20/EPAUNI	Diagnostic file (units)
Output/epu_NEPA20_ch.out	$REP1/NEPA20/EPAUNI	Results file (times)
Output/epu_NEPA20_ch.out2	$REP1/NEPA20/EPAUNI	Results file (format 2)
Output/epu_NEPA20_ch_activity.dia	$REP1/NEPA20/EPAUNI	Diagnostic file (activity)
Output/epu_NEPA20_rh.dat	$REP1/NEPA20/EPAUNI	Results file
Output/epu_NEPA20_rh.dia	$REP1/NEPA20/EPAUNI	Diagnostic file (units)

File	Repository	Comment
Output/epu_NEPA20_rh.out	$REP1/NEPA20/EPAUNI	Results file (times)
Output/epu_NEPA20_rh.out2	$REP1/NEPA20/EPAUNI	Results file (format 2)
Output/epu_NEPA20_rh_activity.dia	$REP1/NEPA20/EPAUNI	Diagnostic file (activity)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-12: EPAUNI Executable File

File	Repository	Comment
Build/Solaris/epauni (Ver:1.19)	$CODE/EPAUNI	Computes decay of radionuclide components in inventory

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.5 BRAGFLO

Table 16-13: BRAGFLO Run Script Files

File	Repository	Comment
RunControl/BRAGFLO.py	$REP1/NEPA20/BRAGFLO	Python run control script
RunControl/BRAGFLOlib.py	$REP1/NEPA20/BRAGFLO	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/BRAGFLO	Run control module
RunControl/Run.py	$REP1/NEPA20/BRAGFLO	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-14: BRAGFLO Input Files

File	Repository	Comment
Input/alg1_bf_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_bf_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/bf1_NEPA20_s*n*.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_NEPA20_s*n*_mod1.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_NEPA20_s*n*_mod2.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf2_NEPA20_closure.dat	$REP1/NEPA20/BRAGFLO	Input file
Input/gm_bf_NEPA20.inp	$REP1/NEPA20/GENMESH	Input file
Input/ic_bf_NEPA20.inp	$REP1/NEPA20/ICSET	Input file
Input/ms_bf_NEPA20.inp	$REP1/NEPA20/MATSET	Input file

Where:

n is 1-6

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-15: BRAGFLO CVS Repositories

CVS Repositories
$CODE/ALGEBRACDB
$CODE/BRAGFLO
$CODE/GENMESH
$CODE/ICSET
$CODE/MATSET
$CODE/POSTBRAG
$CODE/POSTLHS
$CODE/PREBRAG
$REP1/NEPA20/ALGEBRACDB
$REP1/NEPA20/BRAGFLO
$REP1/NEPA20/GENMESH

CVS Repositories
$REP1/NEPA20/ICSET
$REP1/NEPA20/MATSET
$REP1/NEPA20/POSTLHS
$REP1/NEPA20/PREBRAG

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-16: BRAGFLO Log Files

File	Repository	Comment
RunControl/BRAGFLO.log	$REP1/NEPA20/BRAGFLO	Log file
RunControl/BRAGFLO.rtf	$REP1/NEPA20/BRAGFLO	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-17: BRAGFLO Output Files

File	Repository	Comment
Output/alg1_bf_NEPA20_r*i*_v*vvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_bf_NEPA20_r*i*_s*n*_v*vvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/bf2_NEPA20_r*i*_s*n*_v*vvv*.inp	$REP1/NEPA20/PREBRAG	Input file
Output/bf2_NEPA20_r*i*_s*n*_v*vvv*.log	$REP1/NEPA20/BRAGFLO	Log file
Output/bf2_NEPA20_r*i*_s*n*_v*vvv*.sum	$REP1/NEPA20/BRAGFLO	Summary file
Output/bf3_NEPA20_r*i*_s*n*_v*vvv*.cdb	$REP1/NEPA20/BRAGFLO	CDB transfer file; Not saved.
Output/gm_bf_NEPA20.cdb	$REP1/NEPA20/GENMESH	CDB transfer file; Not saved.
Output/ic_bf_NEPA20_r*i*_v*vvv*.cdb	$REP1/NEPA20/ICSET	CDB transfer file; Not saved.
Output/lhs3_bf_NEPA20_r*i*_v*vvv*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/ms_bf_NEPA20.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.

Where:

i is 1-3
n is 1-6
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-18: BRAGFLO Executable Files

File	Repository	Comment
Build/Solaris/algebracdb (Ver:2.36)	$CODE/ALGEBRACDB	Manipulates CAMDAT data by evaluating algebraic expressions
Build/Solaris/bragflo (Ver:7.00)	$CODE/BRAGFLO	Computes brine and gas flow in the repository
Build/Solaris/genmesh (Ver:6.10)	$CODE/GENMESH	Generates the CAMDAT computational grid
Build/Solaris/icset (Ver:2.23)	$CODE/ICSET	Assigns initial conditions to the CAMDAT grid elements
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/postbrag (Ver:4.02)	$CODE/POSTBRAG	Post-processes data for bragflo
Build/Solaris/postlhs (Ver:4.11)	$CODE/POSTLHS	Assigns sampled parameters to the grid blocks and elements
Build/Solaris/prebrag (Ver:9.00)	$CODE/PREBRAG	Pre-processes data for bragflo

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.6 PANEL

Table 16-19: PANEL Run Script Files

File	Repository	Comment
RunControl/PANEL.py	$REP1/NEPA20/PANEL	Python run control script
RunControl/PANELlib.py	$REP1/NEPA20/PANEL	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/PANEL	Run control module
RunControl/Run.py	$REP1/NEPA20/PANEL	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-20: PANEL Input Files

File	Repository	Comment
Input/alg1_panel_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Output/alg2_bf_NEPA20_*ri_sn_vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Input/alg2_panel_NEPA20_b1.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_panel_NEPA20_b2.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_panel_NEPA20_b3.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_panel_NEPA20_b4.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_panel_NEPA20_b5.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_panel_NEPA20_b1.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_panel_NEPA20_b2.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_panel_NEPA20_b3.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_panel_NEPA20_b4.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_panel_NEPA20_b5.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/gm_panel_NEPA20.inp	$REP1/NEPA20/GENMESH	Input file
Input/ms_panel_NEPA20.inp	$REP1/NEPA20/MATSET	Input file
Input/sum_panel_con.inp	$REP1/NEPA20/SUMMARIZE	Input file
Input/sum_panel_int.inp	$REP1/NEPA20/SUMMARIZE	Input file
Input/sum_panel_st.inp	$REP1/NEPA20/SUMMARIZE	Input file

Where:

i is 1-3
n is 1-6
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-21: PANEL CVS Repositories

CVS Repositories
$CODE/ALGEBRACDB
$CODE/GENMESH
$CODE/MATSET
$CODE/PANEL
$CODE/POSTLHS
$CODE/SUMMARIZE
$REP1/NEPA20/ALGEBRACDB
$REP1/NEPA20/GENMESH
$REP1/NEPA20/MATSET
$REP1/NEPA20/PANEL
$REP1/NEPA20/POSTLHS
$REP1/NEPA20/SUMMARIZE

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-22: PANEL Log Files

File	Repository	Comment
RunControl/PANEL.log	$REP1/NEPA20/PANEL	Log file
RunControl/PANEL.rtf	$REP1/NEPA20/PANEL	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-23: PANEL Output Files

File	Repository	Comment
Output/alg1_panel_NEPA20.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_panel_NEPA20_b1.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_panel_NEPA20_b2.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_panel_NEPA20_b3.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_panel_NEPA20_b4.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_panel_NEPA20_b5.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_panel_NEPA20_b1_*rj*_*vwww*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_panel_NEPA20_b2_*rj*_*vwww*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_panel_NEPA20_b3_*rj*_*vwww*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_panel_NEPA20_b4_*rj*_*vwww*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_panel_NEPA20_b5_*rj*_*vwww*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/gm_panel_NEPA20.cdb	$REP1/NEPA20/GENMESH	CDB transfer file; Not saved.
Output/lhs3_panel_NEPA20_b1_*rj*_*vwww*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/lhs3_panel_NEPA20_b2_*rj*_*vwww*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/lhs3_panel_NEPA20_b3_*rj*_*vwww*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/lhs3_panel_NEPA20_b4_*rj*_*vwww*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/lhs3_panel_NEPA20_b5_*rj*_*vwww*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/ms_panel_NEPA20.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.
Output/panel_con_NEPA20_b1_*rj*_*sq*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_con_NEPA20_b2_*rj*_*sq*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_con_NEPA20_b3_*rj*_*sq*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_con_NEPA20_b4_*rj*_*sq*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_con_NEPA20_b5_*rj*_*sq*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_decay_NEPA20_*ri*_*sn*_*vvvv*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_int_NEPA20_b1_*rj*_*so*_*ttttt*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_int_NEPA20_b2_*rj*_*so*_*ttttt*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_int_NEPA20_b3_*rj*_*so*_*ttttt*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_int_NEPA20_b4_*rj*_*so*_*ttttt*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/panel_int_NEPA20_b5_*rj*_*so*_*ttttt*_*vwww*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.
Output/sum_panel_con_NEPA20_b1_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b2_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b3_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b4_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b5_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b1_*rj*_*so*_*ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b2_*rj*_*so*_*ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b3_*rj*_*so*_*ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b4_*rj*_*so*_*ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b5_*rj*_*so*_*ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b1_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b2_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b3_*rj*_*sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file

File	Repository	Comment
Output/sum_panel_st_NEPA20_b4_*rj_sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b5_*rj_sp*.tbl	$REP1/NEPA20/SUMMARIZE	Table file

Where:

i is 1
j is 1-3
n is 1
o is 6
p is 1-2
q is 1-6
ttttt is 00100, 00350, 01000, 02000, 04000, 06000, 09000
vvv is 001
www is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-24: PANEL Executable Files

File	Repository	Comment
Build/Solaris/algebracdb (Ver:2.36)	$CODE/ALGEBRACDB	Manipulates CAMDAT data by evaluating algebraic expressions
Build/Solaris/genmesh (Ver:6.10)	$CODE/GENMESH	Generates the CAMDAT computational grid
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/panel (Ver:5.00)	$CODE/PANEL	Computes release concentrations of nuclides from repository
Build/Solaris/postlhs (Ver:4.11)	$CODE/POSTLHS	Assigns sampled parameters to the grid blocks and elements
Build/Solaris/summarize (Ver:3.02)	$CODE/SUMMARIZE	Writes tables of data from many CAMDAT files

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.7 NUTS

Table 16-25: NUTS Run Script Files

File	Repository	Comment
RunControl/NUTS.py	$REP1/NEPA20/NUTS	Python run control script
RunControl/NUTSlib.py	$REP1/NEPA20/NUTS	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/NUTS	Run control module
RunControl/Run.py	$REP1/NEPA20/NUTS	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-26: NUTS Input Files

File	Repository	Comment
Input/alg_nut_iso_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg_nut_scn_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Output/bf2_NEPA20_*ri_sn_vvvv*.inp	$REP1/NEPA20/PREBRAG	Input file
Output/bf3_NEPA20_*ri_sn_vvvv*.cdb	$REP1/NEPA20/BRAGFLO	CDB transfer file; Not saved.
Input/ms_nut_NEPA20.inp	$REP1/NEPA20/MATSET	Input file
Input/nut_int_NEPA20_*so_ttttt*.inp	$REP1/NEPA20/NUTS	Input file
Input/nut_iso_NEPA20_*sn*.inp	$REP1/NEPA20/NUTS	Input file
Input/nut_scn_NEPA20_*sn*.inp	$REP1/NEPA20/NUTS	Input file
Output/panel_con_NEPA20_b1_*ri_sn_vvvv*.cdb	$REP1/NEPA20/PANEL	CDB transfer file; Not saved.

Where:

i is 1-3

n is 1-5
o is 2-5
ttttt is 00100 for S2, S4
03000, 05000, 07000, 09000 for S3, S5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-27: NUTS CVS Repositories

CVS Repositories
$CODE/ALGEBRACDB
$CODE/MATSET
$CODE/NUTS
$CODE/SCREEN_NUTS
$CODE/SUMMARIZE
$REP1/NEPA20/ALGEBRACDB
$REP1/NEPA20/BRAGFLO
$REP1/NEPA20/MATSET
$REP1/NEPA20/NUTS
$REP1/NEPA20/PANEL
$REP1/NEPA20/PREBRAG
$REP1/NEPA20/SCREEN_NUTS
$REP1/NEPA20/SUMMARIZE

Where:
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-28: NUTS Log File

File	Repository	Comment
RunControl/NUTS.log	$REP1/NEPA20/NUTS	Log file
RunControl/NUTS.rtf	$REP1/NEPA20/NUTS	Formatted log file (Word file)

Where:
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-29: NUTS Output Files

File	Repository	Comment
Output/alg_nut_int_NEPA20_r*i*_s*o*_t*ttttt*_V*VVV*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg_nut_iso_NEPA20_r*i*_s*n*_V*VVV*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg_nut_scn_NEPA20_r*i*_s*n*_v*vvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/ms_nut_NEPA20_r*i*_s*n*_V*VVV*.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.
Output/nut_int_NEPA20_r*i*_s*o*_t*ttttt*_V*VVV*.cdb	$REP1/NEPA20/NUTS	CDB transfer file; Not saved.
Output/nut_iso_NEPA20_r*i*_s*n*_V*VVV*.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.
Output/nut_scn_NEPA20_r*i*_s*n*_v*vvv*.cdb	$REP1/NEPA20/NUTS	CDB transfer file; Not saved.
Output/screen_nut_scn_NEPA20_r*i*_EDIT.inp	$REP1/NEPA20/SCREEN_NUTS	Input file
Output/screen_nut_scn_NEPA20_r*i*_s*n*.out	$REP1/NEPA20/SCREEN_NUTS	Output file
Output/sum_nut_NEPA20_r*i*_s*n*_t*uuuuu*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_nut_scn_NEPA20_r*i*_s*n*.tbl	$REP1/NEPA20/SUMMARIZE	Table file

Where:
i is 1-3
n is 1-5
o is 2-5
ttttt is 00100 for S2, S4
03000, 05000, 07000, 09000 for S3, S5

uuuuu is 00100 for s1
00100, 00350 for S2,S4
01000, 03000, 05000, 07000, 09000 for S3, S5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
VVV are the screened-in vectors listed in Table 6.

Table 16-30: NUTS Screened-In Vectors

Replicate	Scenario	Vectors
1	1	1,2,5,6,7,8,9,10,12,13,14,17,19,20,22,23,24,25,26,27,29,30,34,35,36,41,43,44,45,46,47,50,51,52,53,54,55,58,59,60,61,62,64,66,67,69,70,71,76,78,79,80,82,83,84,86,88,89,93,96,98
1	2	1,2,5,6,7,8,9,10,12,13,14,17,19,20,22,23,24,25,26,27,29,30,34,35,36,41,43,44,45,46,47,50,51,52,53,54,55,58,59,60,61,62,64,66,67,69,70,71,76,78,79,80,82,83,84,86,88,89,93,96,98
1	3	1,2,5,6,7,9,12,13,14,17,20,22,23,24,25,26,27,29,30,34,35,36,41,43,44,45,46,47,50,51,52,54,55,59,60,61,62,64,66,67,70,71,76,78,80,83,84,88,89,96,98
1	4	7,9,22,36,45,53
1	5	7,9,22,36,45,53
2	1	3,4,6,8,12,14,16,17,18,19,21,24,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,43,44,45,48,49,50,51,52,53,54,55,56,59,63,65,67,68,71,74,75,77,79,80,83,84,87,89,90,92,94,95,96,98,99,100
2	2	3,4,6,8,12,14,16,17,18,19,21,24,25,27,28,29,30,31,32,33,34,35,36,37,38,40,41,43,44,48,49,50,51,52,53,54,55,56,59,63,65,67,68,71,74,75,77,79,80,83,84,87,89,90,92,94,95,96,98,99,100
2	3	4,6,8,12,14,16,17,18,19,21,24,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,43,44,45,48,49,50,52,55,56,59,65,67,68,71,74,75,77,79,80,84,87,89,90,94,95,96,98,100
2	4	4,17,21,24,28,34,68
2	5	4,17,24,34,68
3	1	2,3,7,10,11,14,15,18,21,22,24,26,27,28,30,32,33,34,37,39,40,42,43,44,45,47,49,50,53,56,57,58,59,61,62,63,64,65,66,67,68,69,70,71,73,74,75,77,78,79,81,83,84,86,88,89,90,91,93,94,96,97,99,100
3	2	2,3,7,10,11,14,15,18,21,22,24,26,27,28,30,32,33,34,37,39,40,42,43,44,45,47,49,50,53,56,57,58,59,61,62,63,64,65,66,67,68,69,70,71,73,74,75,77,78,79,81,83,84,86,88,89,90,91,93,94,96,97,99,100
3	3	3,7,10,14,18,21,26,27,30,32,33,34,37,39,40,42,43,44,45,47,49,50,53,56,57,58,59,61,62,63,64,65,66,67,68,69,71,74,75,77,78,79,86,88,89,90,91,93,94,96,97,99,100
3	4	42,66,91,93
3	5	42,66,91,93

Table 16-31: NUTS Executable Files

File	Repository	Comment
Build/Solaris/algebracdb (Ver:2.36)	$CODE/ALGEBRACDB	Manipulates CAMDAT data by evaluating algebraic expressions
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/nuts (Ver:2.07)	$CODE/NUTS	Nuclide Transport system model
Build/Solaris/screen_nuts (Ver:1.02)	$CODE/SCREEN_NUTS	Executable file
Build/Solaris/summarize (Ver:3.02)	$CODE/SUMMARIZE	Writes tables of data from many CAMDAT files

Where:
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.8 CUTTINGS_S

Table 16-32: CUTTINGS_S Run Script Files

File	Repository	Comment
RunControl/CUTTINGS_S.py	$REP1/NEPA20/CUTTINGS_S	Python run control script
RunControl/CUTTINGS_Slib.py	$REP1/NEPA20/CUTTINGS_S	Python run control script class modules

File	Repository	Comment
RunControl/rc.py	$REP1/NEPA20/CUTTINGS_S	Run control module
RunControl/Run.py	$REP1/NEPA20/CUTTINGS_S	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-33: CUTTINGS_S Input Files

File	Repository	Comment
Output/bf3_NEPA20_*ri*_*sn*_*vvvv*.cdb	$REP1/NEPA20/BRAGFLO	CDB transfer file; Not saved.
Input/cusp_NEPA20.inp	$REP1/NEPA20/CUTTINGS_S	Input file
Input/gm_cusp_NEPA20.inp	$REP1/NEPA20/GENMESH	Input file
Input/ms_cusp_NEPA20.inp	$REP1/NEPA20/MATSET	Input file
Output/mspall_drs_PABC09_*ri*.out	$REP1/PABC09/DRSPALL	Input file

Where:

i is 1-3
n is 1-5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-34: CUTTINGS_S CVS Repositories

CVS Repositories
$CODE/CUTTINGS_S
$CODE/GENMESH
$CODE/MATSET
$CODE/POSTLHS
$REP1/NEPA20/BRAGFLO
$REP1/NEPA20/CUTTINGS_S
$REP1/NEPA20/GENMESH
$REP1/NEPA20/MATSET
$REP1/NEPA20/POSTLHS
$REP1/PABC09/DRSPALL

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-35: CUTTINGS_S Log Files

File	Repository	Comment
RunControl/CUTTINGS_S.log	$REP1/NEPA20/CUTTINGS_S	Log file
RunControl/CUTTINGS_S.rtf	$REP1/NEPA20/CUTTINGS_S	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-36: CUTTINGS_S Output Files

File	Repository	Comment
Output/cusp_NEPA20_master_*ri*.inp	$REP1/NEPA20/CUTTINGS_S	Input file
Output/cusp_NEPA20_*ri*.tbl	$REP1/NEPA20/CUTTINGS_S	Table file
Output/cusp_NEPA20_*ri*_*sn*_*ttttt*_L_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Output/cusp_NEPA20_*ri*_*sn*_*ttttt*_M_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Output/cusp_NEPA20_*ri*_*sn*_*ttttt*_U_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Output/gm_cusp_NEPA20.cdb	$REP1/NEPA20/GENMESH	CDB transfer file; Not saved.
Output/lhs3_cusp_NEPA20_*ri*_*vvvv*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/ms_cusp_NEPA20.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.

Where:

i is 1-3
n is 1-5
ttttt is 00100, 00350, 01000, 03000, 05000, 10000 for S1
00550, 00750, 02000, 04000, 10000 for S2, S4
01200, 01400, 03000, 05000, 10000 for S3, S5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-37: CUTTINGS_S Executable Files

File	Repository	Comment
Build/Solaris/cuttings_s (Ver:6.03)	$CODE/CUTTINGS_S	Computes cuttings/spall generated by drilling
Build/Solaris/genmesh (Ver:6.10)	$CODE/GENMESH	Generates the CAMDAT computational grid
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/postlhs (Ver:4.11)	$CODE/POSTLHS	Assigns sampled parameters to the grid blocks and elements

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.9 BRAGFLO_DBR

Table 16-38: BRAGFLO_DBR Run Script Files

File	Repository	Comment
RunControl/BRAGFLO_DBR.py	$REP1/NEPA20/BRAGFLO_DBR	Python run control script
RunControl/BRAGFLO_DBRlib.py	$REP1/NEPA20/BRAGFLO_DBR	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/BRAGFLO_DBR	Run control module
RunControl/Run.py	$REP1/NEPA20/BRAGFLO_DBR	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-39: BRAGFLO_DBR Input Files

File	Repository	Comment
Input/alg1_dbr_NEPA20.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg2_dbr_NEPA20_*so*.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_dbr_NEPA20_L.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_dbr_NEPA20_M.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/alg3_dbr_NEPA20_U.inp	$REP1/NEPA20/ALGEBRACDB	Input file
Input/bf1_dbr_NEPA20_L.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_dbr_NEPA20_M.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_dbr_NEPA20_*sn*_100_L.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_dbr_NEPA20_*sn*_100_M.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_dbr_NEPA20_*sn*_100_U.inp	$REP1/NEPA20/PREBRAG	Input file
Input/bf1_dbr_NEPA20_U.inp	$REP1/NEPA20/PREBRAG	Input file
Output/bf3_NEPA20_*ri*_*so*_*vvvv*.cdb	$REP1/NEPA20/BRAGFLO	CDB transfer file; Not saved.
Output/cusp_NEPA20_*ri*_*so*_*ttttt*_L_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Output/cusp_NEPA20_*ri*_*so*_*ttttt*_M_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Output/cusp_NEPA20_*ri*_*so*_*ttttt*_U_*vvvv*.cdb	$REP1/NEPA20/CUTTINGS_S	CDB transfer file; Not saved.
Input/gm_dbr_NEPA20.inp	$REP1/NEPA20/GENMESH	Input file
Input/ic_dbr_NEPA20_*so*.inp	$REP1/NEPA20/ICSET	Input file
Input/ms_dbr_NEPA20.inp	$REP1/NEPA20/MATSET	Input file
Input/rel1_dbr_NEPA20.inp	$REP1/NEPA20/RELATE	Input file
Input/rel2_dbr_NEPA20_*so*.inp	$REP1/NEPA20/RELATE	Input file
Input/sum_dbr.inp	$REP1/NEPA20/SUMMARIZE	Input file

Where:

i is 1-3
n is 1
o is 1-5
tttt is 00100, 00350, 01000, 03000, 05000, 10000 for S1
00550, 00750, 02000, 04000, 10000 for S2, S4
01200, 01400, 03000, 05000, 10000 for S3, S5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-40: BRAGFLO_DBR CVS Repositories

CVS Repositories
$CODE/ALGEBRACDB
$CODE/BRAGFLO
$CODE/GENMESH
$CODE/ICSET
$CODE/MATSET
$CODE/POSTBRAG
$CODE/POSTLHS
$CODE/PREBRAG
$CODE/RELATE
$CODE/SUMMARIZE
$REP1/NEPA20/ALGEBRACDB
$REP1/NEPA20/BRAGFLO
$REP1/NEPA20/BRAGFLO_DBR
$REP1/NEPA20/CUTTINGS_S
$REP1/NEPA20/GENMESH
$REP1/NEPA20/ICSET
$REP1/NEPA20/MATSET
$REP1/NEPA20/PREBRAG
$REP1/NEPA20/RELATE
$REP1/NEPA20/SUMMARIZE

Where:
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-41: BRAGFLO_DBR Log Files

File	Repository	Comment
RunControl/BRAGFLO_DBR.log	$REP1/NEPA20/BRAGFLO_DBR	Log file
RunControl/BRAGFLO_DBR.rtf	$REP1/NEPA20/BRAGFLO_DBR	Formatted log file (Word file)

Where:
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-42: BRAGFLO_DBR Output Files

File	Repository	Comment
Output/alg1_dbr_NEPA20_*ri*_*sn*_*ttttt*_*vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg2_dbr_NEPA20_*ri*_*sn*_*ttttt*_*vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_dbr_NEPA20_*ri*_*sn*_*ttttt*_L_*vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_dbr_NEPA20_*ri*_*sn*_*ttttt*_M_*vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/alg3_dbr_NEPA20_*ri*_*sn*_*ttttt*_U_*vvvv*.cdb	$REP1/NEPA20/ALGEBRACDB	CDB transfer file; Not saved.
Output/bf2_dbr_NEPA20_*ri*_*sn*_*ttttt*_L_*vvvv*.inp	$REP1/NEPA20/BRAGFLO_DBR	Input file
Output/bf2_dbr_NEPA20_*ri*_*sn*_*ttttt*_M_*vvvv*.inp	$REP1/NEPA20/BRAGFLO_DBR	Input file
Output/bf2_dbr_NEPA20_*ri*_*sn*_*ttttt*_U_*vvvv*.inp	$REP1/NEPA20/BRAGFLO_DBR	Input file

File	Repository	Comment
Output/bf3_dbr_NEPA20_*ri*_*sn*_*ttttt*_L_*vvvv*.cdb	$REP1/NEPA20/BRAGFLO_DBR	CDB transfer file; Not saved.
Output/bf3_dbr_NEPA20_*ri*_*sn*_*ttttt*_M_*vvvv*.cdb	$REP1/NEPA20/BRAGFLO_DBR	CDB transfer file; Not saved.
Output/bf3_dbr_NEPA20_*ri*_*sn*_*ttttt*_U_*vvvv*.cdb	$REP1/NEPA20/BRAGFLO_DBR	CDB transfer file; Not saved.
Output/gm_dbr_NEPA20.cdb	$REP1/NEPA20/GENMESH	CDB transfer file; Not saved.
Output/ic_dbr_NEPA20_*ri*_*sn*_*ttttt*_*vvvv*.cdb	$REP1/NEPA20/ICSET	CDB transfer file; Not saved.
Output/ms_dbr_NEPA20.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.
Output/rel1_dbr_NEPA20_*ri*_*sn*_*ttttt*_*vvvv*.cdb	$REP1/NEPA20/RELATE	CDB transfer file; Not saved.
Output/rel2_dbr_NEPA20_*ri*_*sn*_*ttttt*_*vvvv*.cdb	$REP1/NEPA20/RELATE	CDB transfer file; Not saved.
Output/sum_dbr_NEPA20_*ri*_*sn*_*ttttt*_L.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_dbr_NEPA20_*ri*_*sn*_*ttttt*_M.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_dbr_NEPA20_*ri*_*sn*_*ttttt*_U.tbl	$REP1/NEPA20/SUMMARIZE	Table file

Where:

i is 1-3
n is 1-5
tttt is 00100, 00350, 01000, 03000, 05000, 10000 for S1
00550, 00750, 02000, 04000, 10000 for S2, S4
01200, 01400, 03000, 05000, 10000 for S3, S5
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-43: BRAGFLO_DBR Executable Files

File	Repository	Comment
Build/Solaris/algebracdb (Ver:2.36)	$CODE/ALGEBRACDB	Manipulates CAMDAT data by evaluating algebraic expressions
Build/Solaris/bragflo (Ver:7.00)	$CODE/BRAGFLO	Computes brine and gas flow in the repository
Build/Solaris/genmesh (Ver:6.10)	$CODE/GENMESH	Generates the CAMDAT computational grid
Build/Solaris/icset (Ver:2.23)	$CODE/ICSET	Assigns initial conditions to the CAMDAT grid elements
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/postbrag (Ver:4.02)	$CODE/POSTBRAG	Post-processes data for bragflo
Build/Solaris/postlhs (Ver:4.11)	$CODE/POSTLHS	Assigns sampled parameters to the grid blocks and elements
Build/Solaris/prebrag (Ver:9.00)	$CODE/PREBRAG	Pre-processes data for bragflo
Build/Solaris/relate (Ver:1.45)	$CODE/RELATE	Transfers CAMDAT data to another CAMDAT file
Build/Solaris/summarize (Ver:3.02)	$CODE/SUMMARIZE	Writes tables of data from many CAMDAT files

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.10 CCDFGF

Table 16-44: CCDFGF Run Script Files

File	Repository	Comment
RunControl/CCDFGF.py	$REP1/NEPA20/CCDFGF	Python run control script
RunControl/CCDFGFlib.py	$REP1/NEPA20/CCDFGF	Python run control script class modules
RunControl/rc.py	$REP1/NEPA20/CCDFGF	Run control module
RunControl/Run.py	$REP1/NEPA20/CCDFGF	Main control script

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-45: CCDFGF Input Files

File	Repository	Comment
Input/ccgf_NEPA20_control_*ri*.inp	$REP1/NEPA20/CCDFGF	Input file
Output/cusp_NEPA20_*ri*.tbl	$REP1/NEPA20/CUTTINGS_S	Table file
Output/epu_NEPA20_ch.dat	$REP1/NEPA20/EPAUNI	Table file
Output/epu_NEPA20_rh.dat	$REP1/NEPA20/EPAUNI	Table file
Input/gm_ccgf_NEPA20.inp	$REP1/NEPA20/GENMESH	Input file
Input/intrusiontimes.in	$REP1/NEPA20/PRECCDFGF	Input file
Input/ms_ccgf_NEPA20.inp	$REP1/NEPA20/MATSET	Input file
Output/sum_dbr_NEPA20_*ri_so_tvvvvv*_L.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_dbr_NEPA20_*ri_so_tvvvvv*_M.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_dbr_NEPA20_*ri_so_tvvvvv*_U.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_nut_NEPA20_*ri_so_tuuuuu*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b1_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b2_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b3_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b4_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_con_NEPA20_b5_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_int_NEPA20_b1_*ri_sp_ttttt*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b1_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b2_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b3_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b4_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_panel_st_NEPA20_b5_*ri_sn*.tbl	$REP1/NEPA20/SUMMARIZE	Table file
Output/sum_st2d_PABC09_*ri*_mf.tbl	$REP1/PABC09/SUMMARIZE	Table file
Output/sum_st2d_PABC09_*ri*_mp.tbl	$REP1/PABC09/SUMMARIZE	Table file

Where:

i is 1-3
n is 1-2
o is 1-5
p is 6
ttttt is 00100, 00350, 01000, 02000, 04000, 06000, 09000
uuuuu is 00100 for S1
00100, 00350 for S2,S4
01000, 03000, 05000, 07000, 09000 for S3, S5
vvvvv is 00100, 00350, 01000, 03000, 05000, 10000 for S1
00550, 00750, 02000, 04000, 10000 for S2, S4
01200, 01400, 03000, 05000, 10000 for S3, S5
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-46: CCDFGF CVS Repositories

CVS Repositories
$CODE/CCDFGF
$CODE/CCDFVECTORSTATS
$CODE/GENMESH
$CODE/MATSET
$CODE/POSTLHS
$CODE/PRECCDFGF
$REP1/NEPA20/CCDFGF
$REP1/NEPA20/CUTTINGS_S
$REP1/NEPA20/EPAUNI
$REP1/NEPA20/GENMESH
$REP1/NEPA20/MATSET

CVS Repositories
$REP1/NEPA20/POSTLHS
$REP1/NEPA20/PRECCDFGF
$REP1/NEPA20/SUMMARIZE
$REP1/PABC09/SUMMARIZE

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES
$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

Table 16-47: CCDFGF Log Files

File	Repository	Comment
RunControl/CCDFGF.log	$REP1/NEPA20/CCDFGF	Log file
RunControl/CCDFGF.rtf	$REP1/NEPA20/CCDFGF	Formatted log file (Word file)

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-48: CCDFGF Output Files

File	Repository	Comment
Output/ccgf_NEPA20_reltab_*ri*.dat	$REP1/NEPA20/PRECCDFGF	Results file
Output/ccgf_NEPA20_*ri*.out	$REP1/NEPA20/CCDFGF	Results file
Output/gm_ccgf_NEPA20.cdb	$REP1/NEPA20/GENMESH	CDB transfer file; Not saved.
Output/lhs3_ccgf_NEPA20_*ri*_*vvvv*.cdb	$REP1/NEPA20/POSTLHS	CDB transfer file; Not saved.
Output/ms_ccgf_NEPA20.cdb	$REP1/NEPA20/MATSET	CDB transfer file; Not saved.

Where:

i is 1-3
vvv is 001-100
$REP1 = /nfs/data/CVSLIB/WIPP_ANALYSES

Table 16-49: CCDFGF Executable Files

File	Repository	Comment
Build/Solaris/ccdfgf (Ver:7.04)	$CODE/CCDFGF	Constructs complimentary cumulative distribution functions for radionuclide releases
Build/Solaris/ccdfvectorstats (Ver:1.01)	$CODE/CCDFVECTORSTATS	Executable file
Build/Solaris/genmesh (Ver:6.10)	$CODE/GENMESH	Generates the CAMDAT computational grid
Build/Solaris/matset (Ver:9.24)	$CODE/MATSET	Assigns material properties to CAMDAT grid blocks
Build/Solaris/postlhs (Ver:4.11)	$CODE/POSTLHS	Assigns sampled parameters to the grid blocks and elements
Build/Solaris/preccdfgf (Ver:2.01)	$CODE/PRECCDFGF	Pre-processes data for ccdfgf

Where:

$CODE = /nfs/data/CVSLIB/WIPP_CODES/PA_CODES

16.11 GENII

Unlike other codes used in the NEPA20 analysis, the GENII code was executed on a Sandia Windows system (lfeng10, lfeng10.srn.sandia.gov, Precision 7920 Tower, Intel Xeon Gold 5122 CPU) with the Microsoft Windows 10 Enterprise operating system. Calculations were run in the C:\task\NEPA\dose directory and the dose directory was later moved to /nfs/data/CVSLIB/WIPP_EXTERNAL/NEPA20/Files/NEPA_dose_rev1.zip on santana for long-term storage.

Table 16-50: GENII Input Files

File	ZIP File Location	Comment
r1_a.gid	$REP1/	Input file, rancher pathway, mean output, with U235, U238, contaminated forage/feed
r1_b.gid	$REP1/	Input file, rancher pathway, mean output, with U235, U238, non-contaminated forage/feed
r1_c.gid	$REP1/	Input file, rancher pathway, mean output, no U235, U238, contaminated forage/feed
r1_d.gid	$REP1/	Input file, rancher pathway, mean output, no U235, U238, non-contaminated forage/feed
r2.gid	$REP1/	Input file, rancher pathway, median output, no U235, U238, non-contaminated forage/feed
r3.gid	$REP1/	Input file, rancher pathway, mean input, no U235, U238, non-contaminated forage/feed
r4.gid	$REP1/	Input file, rancher pathway, median input, no U235, U238, non-contaminated forage/feed
g1.gid	$REP1/	Input file, geologist pathway, intrusion at 100 year, RH mean
g2.gid	$REP1/	Input file, geologist pathway, intrusion at 100 year, CH mean
g3.gid	$REP1/	Input file, geologist pathway, intrusion at 100 year, RH median
g4.gid	$REP1/	Input file, geologist pathway, intrusion at 100 year, CH median
g5.gid	$REP1/	Input file, geologist pathway, intrusion at 300 year, RH mean
g6.gid	$REP1/	Input file, geologist pathway, intrusion at 300 year, CH mean
g7.gid	$REP1/	Input file, geologist pathway, intrusion at 400 year, RH median
g8.gid	$REP1/	Input file, geologist pathway, intrusion at 400 year, CH median
d2.gid	$REP1/	Input file, drilling debris pathway, intrusion at 750 year, results mean
d3.gid	$REP1/	Input file, drilling debris pathway, intrusion at 1200 year, results mean
d5.gid	$REP1/	Input file, drilling debris pathway, intrusion at 750 year, results median
d6.gid	$REP1/	Input file, drilling debris pathway, intrusion at 1200 year, results median
d2a.gid	$REP1/	Input file, drilling debris pathway, intrusion at 750 year, parameters mean
d3a.gid	$REP1/	Input file, drilling debris pathway, intrusion at 1200 year, parameters mean
d5a.gid	$REP1/	Input file, drilling debris pathway, intrusion at 750 year, parameters median
d6a.gid	$REP1/	Input file, drilling debris pathway, intrusion at 1200 year, parameters median

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_EXTERNAL/NEPA20/Files/

Table 16-51: GENII Output Files

File	ZIP File Location	Comment
r1_a.epa	$REP1/	Output file, rancher pathway, mean output, with U235, U238, contaminated forage/feed
r1_b.epa	$REP1/	Output file, rancher pathway, mean output, with U235, U238, non-contaminated forage/feed
r1_c.epa	$REP1/	Output file, rancher pathway, mean output, no U235, U238, contaminated forage/feed
r1_d.epa	$REP1/	Output file, rancher pathway, mean output, no U235, U238, non-contaminated forage/feed
r2.epa	$REP1/	Output file, rancher pathway, median output, no U235, U238, non-contaminated forage/feed
r3.epa	$REP1/	Output file, rancher pathway, mean input, no U235, U238, non-contaminated forage/feed
r4.epa	$REP1/	Output file, rancher pathway, median input, no U235, U238, non-contaminated forage/feed
g1.epa	$REP1/	Output file, geologist pathway, intrusion at 100 year, RH mean
g2.epa	$REP1/	Output file, geologist pathway, intrusion at 100 year, CH mean
g3.epa	$REP1/	Output file, geologist pathway, intrusion at 100 year, RH median
g4.epa	$REP1/	Output file, geologist pathway, intrusion at 100 year, CH median
g5.epa	$REP1/	Output file, geologist pathway, intrusion at 300 year, RH mean
g6.epa	$REP1/	Output file, geologist pathway, intrusion at 300 year, CH mean
g7.epa	$REP1/	Output file, geologist pathway, intrusion at 400 year, RH median
g8.epa	$REP1/	Output file, geologist pathway, intrusion at 400 year, CH median
d2.epa	$REP1/	Output file, drilling debris pathway, intrusion at 750 year, results mean
d3.epa	$REP1/	Output file, drilling debris pathway, intrusion at 1200 year, results mean
d5.epa	$REP1/	Output file, drilling debris pathway, intrusion at 750 year, results median
d6.epa	$REP1/	Output file, drilling debris pathway, intrusion at 1200 year, results median
d2a.epa	$REP1/	Output file, drilling debris pathway, intrusion at 750 year, parameters mean
d3a.epa	$REP1/	Output file, drilling debris pathway, intrusion at 1200 year, parameters mean
d5a.epa	$REP1/	Output file, drilling debris pathway, intrusion at 750 year, parameters median
d6a.epa	$REP1/	Output file, drilling debris pathway, intrusion at 1200 year, parameters median

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_EXTERNAL/NEPA20/Files/

Table 16-52: GENII Executable File (GENII v2.10)

File	Archived Location	host	Comment
C:\mysoftware\FRAMES\Fui.exe	$REP1/GENIIsetup2-10-2b.zip	lfeng10.srn.sandia.gov	GENII executable

Where:

$REP1 = /nfs/data/CVSLIB/WIPP_EXTERNAL/NEPA20/Files

16.12 Supplemental Analysis with Mean and Median Input Parameters

As outlined in the NEPA20 planning document (Zeitler et al. 2020), a supplemental analysis was also run, in which two PA calculations were performed, one with means of sampled input parameters and one with medians of sampled input parameters. The same PA code versions were run for the supplemental analysis. Input and output files for the supplemental analysis are located in this directory on the fwm cluster: /data/cvs/CVSLIB/WIPP_EXTERNAL/NEPA20/Files/NEPA20_MM.tar.gz. The file structure for the location of files associated with the supplemental PA calculations in that directory is the same as that for the primary PA calculations described in Sections 16.3 through 16.10. Key assumptions and a comparison of the dose calculations based on the supplemental analysis results are found in Section 13.3.2.

17 Qualification of the GENII Code for Use in NEPA20 Calculations

GENII is an environmental dosimetry computer code and has been chosen to implement dose calculations for the NEPA20 analysis. GENII Version 2.10 is part of the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP) at the U.S. Nuclear Regulatory Commission. It can be downloaded from https://ramp.nrc-gateway.gov/content/genii-overview. The GENII code was developed under NQA-1 procedures. In August 2013, DOE completed an evaluation of GENII V2.10.1 against DOE's safety software quality assurance criteria and this version was listed as a Toolbox code in the safety software Central Registry (https://www.energy.gov/ehss/genii). In order to perform dose calculations for the NEPA20 analysis, the GENII code v. 2.10 was installed on Sandia Windows system desktop, lfeng10 (lfeng10.srn.sandia.gov).

As a functional verification of GENII, the "Chaki and Parks-2000, CAP-88" sample problem was run with GENII version 2 by the developer of the GENII code. There is a detailed comparison and analysis between the results of CAP-88 and GENII in the User's Guide of GENII included with the code download (Napier 2012). The results of this example problem are included with the installation package of GENII version 2 (file ash5.epa in the Example directory, which was generated on 02/21/2017). Successful completion of this problem on the Windows system lfeng10 was chosen as the criteria of the one-time QA testing of GENII for the NEPA20 analysis.

The "Chaki and Parks-2000, CAP-88" sample problem was run on system lfeng10 with local installation of GENII with the same input parameters used in 2017. The local GENII computation result was then compared with the ash5.epa file, the GENII result file produced in 2017.

```
*******************************************************************************
* File:    c:\task\genii_qa\ash5.epa
* Section: nes11
* Date:    4/19/2020 3:49:41 PM
*******************************************************************************

 0,
 1,
---- GENII 2.10.2     Run on: 02-21-2017  at 22:49:26    ------------------------
```

Figure 18-1. Header portion of ash5.epa

```
*******************************************************************************
* File:    c:\task\genii_qa\sandia.epa
* Section: nes11
* Date:    4/19/2020 3:51:35 PM
*******************************************************************************

 0,
 1,
---- GENII 2.10.2     Run on: 04-16-2020  at 18:54:25    ------------------------
```

Figure 18-2. Header portion of sandia.epa

Figure 18-1 is the header portion of file ash5.epa, which was generated on 02/21/2017 and comes with the GENII installation package. Figure 18-2 is the header portion of sandia.epa, the computational result of running the test on the local GENII installation. In addition to the created date, the location of the file is also indicated in the header portion.

```
TIME PERIOD NUMBER  1, CORRESPONDING TO TIME 99.0000 YEARS ------------------------------------------------
MAXIMUM POINT =   1 CORRESPONDING TO DIRECTION   1 AND DISTANCE   1 AT LOCATION X=  0.0 KM; Y=  0.0 KM
INDIVIDUAL AGE RANGE    10 TO   70 YEARS
MAXIMUM EXPOSED INDIVIDUAL LOCATION
ORGAN          MAX. DOSE (rem ) TISSUE      CANCER INCIDENCE    CANCER FATALITIES
total body       8.03E-04       all sites       4.83E-07           4.02E-07

TIME PERIOD NUMBER  1, CORRESPONDING TO TIME 99.0000 YEARS ------------------------------------------------
INDIVIDUAL AGE RANGE 10 TO 70 YEARS
INDIVIDUAL EFFECTIVE DOSE BY DISTANCE AND DIRECTION (rem )
          310.    810.   1500.   2500.   3500.   7500.  15000.  25000.  35000.  45000.
    22. 8.0E-04 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00
    45. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00
    68. 6.5E-04 0.0E+00 0.0E+00 5.5E-05 0.0E+00 0.0E+00 3.5E-06 1.5E-06 8.0E-07 5.1E-07
    90. 0.0E+00 0.0E+00 0.0E+00 5.8E-05 3.4E-05 1.0E-05 3.4E-06 1.5E-06 8.4E-07 5.6E-07
   112. 0.0E+00 0.0E+00 0.0E+00 4.0E-05 0.0E+00 7.7E-06 2.6E-06 1.1E-06 6.2E-07 4.0E-07
   135. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 5.7E-06 1.9E-06 8.5E-07 4.9E-07 3.2E-07
   158. 0.0E+00 0.0E+00 5.9E-05 0.0E+00 0.0E+00 0.0E+00 2.0E-06 8.7E-07 5.0E-07 3.3E-07
   180. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 2.4E-05 7.7E-06 2.6E-06 1.1E-06 6.5E-07 4.2E-07
   202. 0.0E+00 0.0E+00 0.0E+00 2.4E-05 1.4E-05 4.7E-06 1.6E-06 6.7E-07 3.7E-07 2.4E-07
   225. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 2.2E-05 7.1E-06 2.4E-06 1.0E-06 5.7E-07 3.7E-07
   248. 0.0E+00 0.0E+00 8.3E-05 4.2E-05 2.6E-05 8.8E-06 2.9E-06 1.2E-06 6.5E-07 4.0E-07
   270. 0.0E+00 0.0E+00 0.0E+00 5.4E-05 3.5E-05 1.2E-05 4.0E-06 0.0E+00 0.0E+00 0.0E+00
   292. 0.0E+00 0.0E+00 0.0E+00 4.3E-05 0.0E+00 0.0E+00 0.0E+00 1.2E-06 5.7E-07 3.2E-07
   315. 0.0E+00 0.0E+00 7.3E-05 0.0E+00 0.0E+00 0.0E+00 0.0E+00 1.2E-06 5.6E-07 3.2E-07
   338. 0.0E+00 2.5E-04 0.0E+00 6.9E-05 0.0E+00 0.0E+00 0.0E+00 1.9E-06 9.3E-07 5.5E-07
   360. 0.0E+00 0.0E+00 5.3E-04 2.9E-04 0.0E+00 0.0E+00 0.0E+00 8.5E-06 4.3E-06 2.5E-06
```

Figure 18-3. Portion of ash5.epa

```
TIME PERIOD NUMBER  1, CORRESPONDING TO TIME 99.0000 YEARS ------------------------------------------------
MAXIMUM POINT =   1 CORRESPONDING TO DIRECTION   1 AND DISTANCE   1 AT LOCATION X=  0.0 KM; Y=  0.0 KM
INDIVIDUAL AGE RANGE    10 TO   70 YEARS
MAXIMUM EXPOSED INDIVIDUAL LOCATION
ORGAN          MAX. DOSE (rem ) TISSUE      CANCER INCIDENCE    CANCER FATALITIES
total body       8.03E-04       all sites       4.83E-07           4.02E-07

TIME PERIOD NUMBER  1, CORRESPONDING TO TIME 99.0000 YEARS ------------------------------------------------
INDIVIDUAL AGE RANGE 10 TO 70 YEARS
INDIVIDUAL EFFECTIVE DOSE BY DISTANCE AND DIRECTION (rem )
          310.    810.   1500.   2500.   3500.   7500.  15000.  25000.  35000.  45000.
    22. 8.0E-04 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00
    45. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00
    68. 6.5E-04 0.0E+00 0.0E+00 5.5E-05 0.0E+00 0.0E+00 3.5E-06 1.5E-06 8.0E-07 5.1E-07
    90. 0.0E+00 0.0E+00 0.0E+00 5.8E-05 3.4E-05 1.0E-05 3.4E-06 1.5E-06 8.4E-07 5.6E-07
   112. 0.0E+00 0.0E+00 0.0E+00 4.0E-05 0.0E+00 7.7E-06 2.6E-06 1.1E-06 6.2E-07 4.0E-07
   135. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 0.0E+00 5.7E-06 1.9E-06 8.5E-07 4.9E-07 3.2E-07
   158. 0.0E+00 0.0E+00 5.9E-05 0.0E+00 0.0E+00 0.0E+00 2.0E-06 8.7E-07 5.0E-07 3.3E-07
   180. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 2.4E-05 7.7E-06 2.6E-06 1.1E-06 6.5E-07 4.2E-07
   202. 0.0E+00 0.0E+00 0.0E+00 2.4E-05 1.4E-05 4.7E-06 1.6E-06 6.7E-07 3.7E-07 2.4E-07
   225. 0.0E+00 0.0E+00 0.0E+00 0.0E+00 2.2E-05 7.1E-06 2.4E-06 1.0E-06 5.7E-07 3.7E-07
   248. 0.0E+00 0.0E+00 8.3E-05 4.2E-05 2.6E-05 8.8E-06 2.9E-06 1.2E-06 6.5E-07 4.0E-07
   270. 0.0E+00 0.0E+00 0.0E+00 5.4E-05 3.5E-05 1.2E-05 4.0E-06 0.0E+00 0.0E+00 0.0E+00
   292. 0.0E+00 0.0E+00 0.0E+00 4.3E-05 0.0E+00 0.0E+00 0.0E+00 1.2E-06 5.7E-07 3.2E-07
   315. 0.0E+00 0.0E+00 7.3E-05 0.0E+00 0.0E+00 0.0E+00 0.0E+00 1.2E-06 5.6E-07 3.2E-07
   338. 0.0E+00 2.5E-04 0.0E+00 6.9E-05 0.0E+00 0.0E+00 0.0E+00 1.9E-06 9.3E-07 5.5E-07
   360. 0.0E+00 0.0E+00 5.3E-04 2.9E-04 0.0E+00 0.0E+00 0.0E+00 8.5E-06 4.3E-06 2.5E-06
```

Figure 18-4. Portion of sandia.epa

Figure 18-3 is a portion of the file ash5.epa. It lists the maximum dose and individual effective dose at different distances and directions. Figure 18-4 is the corresponding portion of the file sandia.epa. The information in Figures 18-3 and 18-4 are the same.

By comparing the entire file contents of ash5.epa and sandia.epa, it is found that these two files are identical except the date and filename. For the "Chaki and Parks-2000, CAP-88" sample

problem, the local installation of the GENII code on system lfeng10 gives the same result as the code developer obtained in 2017.

This one-time QA test was run in the C:\task\GENII_QA directory on Windows system lfeng10.srn.sandia.gov and the dose directory was later moved to /nfs/data/CVSLIB/WIPP_ANALYSES/NEPA20.

Reference:

1. Napier, B.A. 2012, GENII Version 2 Users' Guide, PNNL-14583, Rev. 4.

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