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TECHNICAL SUPPORT DOCUMENT

FOR SECTIONS 194.23, 194.32, 193.33, AND 194.54 REVIEW OF CHANGES TO WIPP PERFORMANCE ASSESSMENT FEATURES, EVENTS, AND PROCESSES IN THE 2019 CRA

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Center for Waste Management and Regulations
1200 Pennsylvania Ave, NW
Washington, DC 20460

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Executive Summary

A comprehensive review of features, events, and processes (FEPs) potentially relevant to Waste Isolation Pilot Plant (WIPP) repository performance is conducted by the U.S. Department of Energy (DOE) prior to each recertification performance assessment (PA). DOE has grouped FEPs depending on whether they were related to natural, human-induced, or waste-induced causes. Each FEP in the baseline list for the prior recertification PA is accompanied by a screening argument that describes how the FEP affects repository performance modeling and whether it should be addressed in that modeling. For each new recertification, past screening arguments are reviewed for continued relevance and updated as new information becomes available. Those FEPs that are potentially affected by the new information are identified and reviewed to determine if their screening arguments need to be updated to better reflect the changed conditions or if a new FEP needs to be added. Based on the results of this screening process, each FEP in the baseline is either screened in and addressed in PA or is screened out and not addressed. A FEP may be screened out due to a lack of adverse consequence, a low probability of occurrence, or by a regulatory directive. FEPs that are screened out remain in the baseline and are reevaluated prior to each recertification. The list of FEPs approved by the Environmental Protection Agency (EPA) for the CRA-2014 PA was used by DOE as the baseline for identifying FEPs related to changes in the current CRA-2019 PA.

DOE's FEP review concluded that the 245 FEPs in the 2014 baseline adequately addressed the types of features, events, and processes potentially relevant to the CRA-2019 PA and no new FEPs needed to be added. Of the 245 FEPs in the proposed baseline for the CRA-2019 PA, 161 FEPs were unchanged from the CRA-2014 PA and 84 FEPs were updated with new information. EPA provided DOE with completeness questions for many of the updated FEPs to better understand DOE's screening rationale. EPA accepted DOE's screening classifications and arguments for 71 of the 84 FEPs identified by DOE as changed. For the 13 remaining FEPs, the Agency identified residual concerns that are explained in this Technical Support Document (TSD). EPA expects DOE to resolve these concerns in the CRA-2024 FEP baseline review. In addition, EPA has questions concerning several FEPs that the Agency considers to have changed since 2014 but for which DOE had concluded "no change." EPA also recommends that a new FEP be added to the baseline to address a process that has been included in PA (brine consumption by radiolysis) but does not appear to be addressed as a FEP. However, none of the concerns identified by EPA are likely to have a significant impact alone on repository performance.

The following four FEPs may require additional analysis and were identified by EPA as deserving special attention by DOE when preparing the CRA-2024 PA.

FEP N71 Microbes. The role of microbes in facilitating radionuclide transport is a potentially important feature of the Culebra release pathway. The DOE conclusion that microbes are rapidly filtered out in the Culebra is inadequately supported and needs to be reevaluated for the CRA-2024 PA. However, the Agency does not expect this concern to have a significant direct effect on overall repository performance because releases from the Culebra are very low.

FEP H26 Groundwater Extraction. Recent pumping from a private well on the Mills Ranch may alter groundwater flow directions and velocities in the Culebra in a manner that is not currently anticipated in WIPP PA. Although the Agency does not expect this concern to have a significant effect on repository performance because releases from the Culebra are very low in current modeling, the potential impact of this type of groundwater extraction on the Culebra release pathway needs to be reevaluated for the next PA.

FEP H31 Natural Borehole Fluid Flow. The new method used by DOE in the CRA-2019 PA for calculating borehole plugging frequencies has not been accepted by EPA because it is not adequately supported by regulatory considerations or by current practice. An EPA sensitivity study demonstrated the impact of the change in methodology versus the previous method on releases in PA was substantial, however both remained below release limits. EPA expects DOE to revert to the previously-approved methodology for calculating plugging pattern probabilities in the CRA-2024 PA, or otherwise propose alternative methods that may be approved by EPA prior to that time.

FEP W23 Subsidence. DOE's assumption that the effects of subsidence due to repository excavations are intrinsically incorporated in the Culebra transmissivity fields is inadequately supported. EPA is unaware of any documentation describing how Culebra transmissivity fields based on geohydrologic field data have been modified to account for repository-induced subsidence that has not yet occurred. EPA expects that the screening argument for this FEP will be reevaluated for the CRA-2024 PA. With the retardation currently expected in the Culebra, releases through the Culebra are a minor contributor to releases so this issue has limited consequence in the current modeling.

EPA accepts DOE's updated FEP baseline as sufficient for the CRA-2019 PA and expects DOE to address and resolve the issues raised by the Agency in the 2024 FEP baseline review. The Agency's expectation applies to all FEPs identified in this TSD as having residual concerns with special attention given to the four FEPs identified above.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIC	Active Institutional Control
APCS	Abandonment of Panel Closures in South End of Repository
BAB	Brine ‘A’ Bacteria
CAG	Compliance Application Guidance
CARD	Compliance Application Review Document
CCA	Compliance Certification Application
CCO	Criticality Control Overpack
CFR	Code of Federal Regulations
CH	Contact-Handled
CPR	Cellulosics, Plastics, and Rubber
CRA	Compliance Recertification Application
DBE	Design Basis Earthquake
DBDSP	Delaware Basin Drilling Surveillance Program
DBMAR	Delaware Basin Monitoring Annual Report
DOE or the Department	U.S. Department of Energy
DP	Screened in for Disturbed Performance Scenarios
DPA	Deferred Performance Assessment
DRZ	Disturbed Rock Zones
EDTA	Ethylenediaminetetraacetic Acid
EP	Events and Processes
EPA or the Agency	U.S. Environmental Protection Agency
ERMS	Electronic Record Management System
FEPs	Features, Events, and Processes
HCN	Historic, Current, or Near Future
ISA	Isosaccharinic Acid
KIT	Karlsruhe Institute of Technology
LANL	Los Alamos National Laboratory
LWA	Land Withdrawal Area

MB	Marker Bed
NMTSO	New Mexico Tech Seismic Observatory
NROR	North Rest of the Repository
OPS/EXP	Operational and Experimental
PA	Performance Assessment
PAIR	Performance Assessment Inventory Report
PCN	Planned Change Notice
PCS	Panel Closure System
PGA	Peak Ground Acceleration
POP	Pipe Overpack
RH	Remote-Handled
ROM	Run-of-Mine
ROMPCS	Run-of-Mine (Salt) Panel Closure System
SDI	Salt Disposal Investigation
SDDI	Salt Defense Disposal Investigation
SNL	Sandia National Laboratories
SO-C	Screened out based on no, low, or beneficial consequence
SO-P	Screened out based on a very low probability of occurrence
SO-R	Screened out based on a regulatory directive
SP	Specific Procedure
SROR	South Rest of the Repository
TDEM	Time-Domain Electromagnetic
TRU	Transuranic
TSD	Technical Support Document
UP	Screened in for Undisturbed Performance Scenarios
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant
WSM	Worldwide Stress Map

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1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) repository has been developed by the Department of Energy (DOE or the Department) for the permanent disposal of transuranic (TRU) waste. The repository is located in deeply buried deposits of bedded salt in the Salado Formation in southeastern New Mexico. The Environmental Protection Agency (EPA or the Agency) regulates post-closure containment of TRU waste at the WIPP in accordance with the radioactive waste disposal standards at Code of Federal Regulations (CFR) Title 40, Parts 191 and 194. The WIPP was first certified by EPA as complying with these standards and approved for TRU waste disposal in 1998. The WIPP Land Withdrawal Act (LWA) is a federal statute requiring DOE to submit recertification applications to EPA at five-year intervals following the first waste shipment in March 1999, with the most recent recertification application submitted in March 2019. EPA's decision to recertify the WIPP is based in part on the results of an assessment of the projected ability of the facility to meet the Agency's numerical waste isolation standards over a 10,000-year post-closure regulatory time frame.

The ability to meet the Agency's numerical standards is determined by the results of computer modeling conducted for DOE by Sandia National Laboratories (SNL). That modeling simulates the repository's future waste isolation capability in a process called Performance Assessment (PA). The most recent assessment was included in DOE's 2019 Compliance Recertification Application (CRA) and is called the CRA-2019 PA. The CRA-2019 PA was submitted to the Agency in December 2019 (Sosson 2019). That PA, also called the CRA19 PA or the Deferred PA (DPA), was, by Agency agreement, not submitted at the same time as the recertification application. This delay was approved to allow the Department to conserve resources needed to address planned major modifications of the WIPP repository design and the numerical simulations of that design. These modifications are planned to be submitted for independent peer review and subsequent Agency review prior to DOE's 2024 CRA (Veal 2017). Because the CRA-2019 PA was not yet complete at the time DOE's 2019 recertification application was submitted, that application referred to the Agency-approved CRA-2014 PA on an interim basis as the current baseline PA (DOE 2014, Appendix PA-2014). Upon completion, the deferred CRA-2019 PA superseded the CRA-2014 PA and was accepted by the Agency as the DOE's formal, updated demonstration of continuing compliance with EPA's performance requirements.

A methodology for identifying and screening features, events, and processes (FEPs) considered to be potentially important to the WIPP disposal system was used by SNL to help assure that important aspects of the disposal system are accounted for in PA calculations. The methodology was first used at the WIPP for developing the original 1996 Compliance Certification Application (CCA) (DOE 1996, Appendix SCR). The first step in implementation was to develop a comprehensive list of features (such as waste panel dimensions), events (such as earthquakes), and processes (such as halite creep) that could be important to repository performance. Criteria were developed for screening this list to determine which FEPs were likely to be sufficiently important to be addressed in WIPP PA and which were less likely to affect repository performance. FEPs that were determined to be addressed in PA were identified as screened in, and FEPs that were less important to repository performance and not addressed in PA were identified as screened out. A FEP may be screened out due to a lack of adverse

consequence, a low probability of occurrence, or by a regulatory directive. FEPs that were not initially screened out were addressed in the 1996 CCA PA.

The entire list of FEPs and their screening arguments, including those that were screened in as well as those that were screened out, was identified as the CCA FEP baseline. That baseline was reviewed for continued relevance to the subsequent 2004 WIPP CRA and an updated baseline was developed incorporating the changes. A similar process has been followed for each subsequent recertification to determine if the previous screening arguments and decisions remained appropriate considering the effects of changes in features, events, and processes that had occurred in the interim. Such changes may occur, for example, as a result of revisions to the repository design, new human activities in the repository vicinity that could affect performance, an updated repository waste inventory, and new scientific information. FEP baseline reviews can result in new FEPs being added to the list, existing FEPs being combined or partitioned, previously screened-out FEPs being screened in, and previously screened-in FEPs being screened out. In this manner a new FEP baseline is developed for each subsequent CRA, replacing the previous baseline.

SNL has developed the following system for classifying the results of the FEP screening process.

- DP Screened in for disturbed performance (borehole intrusion) scenarios
- UP Screened in for undisturbed performance (no borehole intrusions) scenarios
- SO-C Screened out based on no, low, or beneficial consequence
- SO-P Screened out based on a very low probability of occurrence
- SO-R Screened out based on a regulatory directive

The FEP baseline prepared by SNL for the CRA-2014 PA (DOE 2014, Appendix SCR-2014) is the most recent baseline that has been reviewed and approved by the Agency (EPA 2017a). That baseline consisted of 245 FEPs and was divided into three categories: 70 FEPs were related to the external natural environment such as earthquakes (prefix N); 61 FEPs were related to external human-induced conditions such as potash mining (prefix H); and 114 FEPs were related to internal waste and repository conditions such as changes in the waste inventory (prefix W). A complete list of FEPs in SNL's CRA-2019 FEP baseline is presented in Table 1.

EPA considers a thorough review and update of the previous FEP baseline to be an important part of ensuring that the WIPP PA remains relevant to current conditions that may affect repository performance. The screening arguments presented in the FEP baseline should provide a description of the features, events, and processes that are reviewed and considered to have the potential to affect repository performance. A thorough discussion of the basis for the screening decision, supplemented by references to additional details on how screened-in FEPs are incorporated into WIPP PA, provides an overview of how future repository performance is assessed.

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
N1	Stratigraphy	No change	No	UP
N2	Brine Reservoirs	Updated by referencing new PA parameter GLOBAL:PBRINE	No	DP
N3	Changes in Regional Stress	No change	No	SO-C
N4	Regional Tectonics	No change	No	SO-C
N5	Regional Uplift and Subsidence	No change	No	SO-C
N6	Salt Deformation	No change	No	SO-P
N7	Diapirism	No change	No	SO-P
N8	Formation of Fractures	No change	No	SO-P UP (Repository)
N9	Changes in Fracture Properties	No change	No	SO-C UP (Near Repository)
N10	Formation of New Faults	No change	No	SO-P
N11	Fault Movement	No change	No	SO-P
N12	Seismic Activity	Updated with new seismic data	No	UP
N13	Volcanic Activity	No change	No	SO-P
N14	Magmatic Activity	No change	No	SO-C
N15	Metamorphic Activity	No change	No	SO-P
N16	Shallow Dissolution	No change	No	UP
N18	Deep Dissolution	No change	No	SO-P
N20	Breccia Pipes	No change	No	SO-P
N21	Collapse Breccias	No change	No	SO-P
N22	Fracture Infills	No change	No	SO-C - Beneficial

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
N23	Saturated Groundwater Flow	No change	No	UP
N24	Unsaturated Groundwater Flow	No change	No	UP
N25	Fracture Flow	No change	No	UP
N27	Effects of Preferential Pathways	No change	No	UP
N26	Density Effects on Groundwater Flow	No change	Yes	SO-C – Beneficial
N28	Thermal Effects on Groundwater Flow	No change	No	SO-C
N29	Saline Intrusion (Hydrogeological Effects)	No change	No	SO-P
N30	Freshwater Intrusion (Hydrogeological Effects)	No change	No	SO-P
N31	Hydrological Response to Earthquakes	No change	No	SO-C
N32	Natural Gas Intrusion	No change	No	SO-P
N33	Groundwater Geochemistry	No change	No	UP
N34	Saline Intrusion (Geochemical Effects)	No change	No	SO-C
N38	Effects of Dissolution	No change	No	SO-C
N35	Freshwater Intrusion (Geochemical Effects)	No change	No	SO-C
N36	Changes in Groundwater Eh	No change	No	SO-C
N37	Changes in Groundwater pH	No change	No	SO-C
N39	Physiography	No change	No	UP
N40	Impact of a Large Meteorite	No change	No	SO-P
N41	Mechanical Weathering	No change	No	SO-C
N42	Chemical Weathering	No change	No	SO-C
N43	Aeolian Erosion	No change	No	SO-C
N44	Fluvial Erosion	No change	No	SO-C
N45	Mass Wasting (Erosion)	No change	No	SO-C
N46	Aeolian Deposition	No change	No	SO-C
N47	Fluvial Deposition	No change	No	SO-C
N48	Lacustrine Deposition	No change	No	SO-C
N49	Mass Wasting (Deposition)	No change	No	SO-C
N50	Soil Development	No change	No	SO-C
N51	Stream and River Flow	No change	No	SO-C

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
N52	Surface Water Bodies	No change	No	SO-C
N53	Groundwater Discharge	No change	No	UP
N54	Groundwater Recharge	No change	No	UP
N55	Infiltration	No change	No	UP
N56	Changes in Groundwater Recharge and Discharge	No change	No	UP
N57	Lake Formation	No change	No	SO-C
N58	River Flooding	No change	No	SO-C
N59	Precipitation (e.g., Rainfall)	No change	No	UP
N60	Temperature	No change	No	UP
N61	Climate Change	No change	No	UP
N62	Glaciation	No change	No	SO-P
N63	Permafrost	No change	No	SO-P
N64	Seas and Oceans	No change	No	SO-C
N65	Estuaries	No change	No	SO-C
N66	Coastal Erosion	No change	No	SO-C
N67	Marine Sediment Transport and Deposition	No change	No	SO-C
N68	Sea Level Changes	No change	No	SO-C
N69	Plants	No change	No	SO-C
N70	Animals	No change	No	SO-C
N71	Microbes	Edited for clarity and updated experimental references	No	SO-C (UP - for colloidal effects and gas generation)
N72	Natural Ecological Development	No change	No	SO-C
H1	Oil and Gas Exploration	Updated with new drilling rate	No	SO-C (HCN) DP (Future)
H2	Potash Exploration	No change	No	SO-C (HCN) DP (Future)
H4	Oil and Gas Exploitation	Updated with new drilling rate	No	SO-C (HCN) DP (Future)
H8	Other Resources	No change	No	SO-C (HCN) DP (Future)
H9	Enhanced Oil and Gas Recovery	No change	No	SO-C (HCN) DP (Future)

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
H3	Water Resources Exploration	Updated with most recent monitoring information	No	SO-C (HCN) SO-C (Future)
H5	Groundwater Exploitation	Updated with most recent monitoring information	No	SO-C (HCN) SO-C (Future)
H6	Archaeological Investigations	No change	No	SO-R (HCN) SO-R (Future)
H7	Geothermal	No change	No	SO-R (HCN) SO-R (Future)
H10	Liquid Waste Disposal	No change	No	SO-R (HCN) SO-R (Future)
H11	Hydrocarbon Storage	No change	No	SO-R (HCN) SO-R (Future)
H12	Deliberate Drilling Intrusion	No change	No	SO-R (HCN) SO-R (Future)
H13	Conventional Underground Potash Mining	No change	No	UP (HCN) DP (Future)
H14	Other Resources (Mining For)	No change	No	SO-C (HCN) SO-R (Future)
H15	Tunneling	No change	No	SO-R (HCN) SO-R (Future)
H16	Construction of Underground Facilities (For Example Storage, Disposal, Accommodation)	No change	No	SO-R (HCN) SO-R (Future)
H17	Archaeological Excavations	No change	No	SO-C (HCN) SO-R (Future)
H18	Deliberate Mining Intrusion	No change	No	SO-R (HCN) SO-R (Future)
H19	Explosions for Resource Recovery	No change	No	SO-C (HCN) SO-R (Future)
H20	Underground Nuclear Device Testing	No change	No	SO-C (HCN) SO-R (Future)
H21	Drilling Fluid Flow	Updated to justify the exclusion of northern experimental area of mined area from intrusion.	No	SO-C (HCN) DP (Future)
H22	Drilling Fluid Loss	Updated to justify the exclusion of northern experimental area of mined area from intrusion.	No	SO-C (HCN) DP (Future)

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
H23	Blowouts	Updated with new parameter GLOBAL:PBRINE	No	SO-C (HCN) DP (Future)
H24	Drilling-Induced Geochemical Changes	No change	No	UP (HCN) DP (Future)
H25	Oil and Gas Extraction	No change	No	SO-C (HCN) SO-R (Future)
H26	Groundwater Extraction	No change	No	SO-C (HCN) SO-R (Future)
H27	Liquid Waste Disposal–Outside Boundary (OB)	No change	No	SO-C (HCN) SO-C (Future)
H28	Enhanced Oil and Gas Production–OB	Updated per EPA comment regarding enhanced oil and gas production techniques in the Delaware Basin.	No	SO-C (HCN) SO-C (Future)
H29	Hydrocarbon Storage–OB	No change	No	SO-C (HCN) SO-C (Future)
H60	Liquid Waste Disposal–Inside Boundary (IB)	No change	No	SO-R (HCN) SO-R (Future)
H61	Enhanced Oil and Gas Production–IB	No change	No	SO-R (HCN) SO-R (Future)
H62	Hydrocarbon Storage–IB	No change	No	SO-R (HCN) SO-R (Future)
H30	Fluid-Injection Induced Geochemical Changes	No change	No	UP (HCN) SO-R (Future)
H31	Natural Borehole Fluid Flow	Updated to reflect BRAGFLO corrections for open borehole parameters and to reflect new plugging probabilities.	No	SO-C (HCN) SO-C (Future, holes not penetrating waste panels) DP (Future, holes penetrating panels)
H32	Waste-Induced Borehole Flow	Updated to reflect new plugging probabilities.	No	SO-R (HCN) DP (Future)
H34	Borehole-Induced Solution and Subsidence	No change	No	SO-C (HCN) SO-C (Future)
H35	Borehole-Induced Mineralization	No change	No	SO-C (HCN) SO-C (Future)

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
H36	Borehole-Induced Geochemical Changes	No change	Yes	UP (HCN) DP (Future) SO-C – Beneficial (for units other than the Culebra)
H37	Changes in Groundwater Flow Due to Mining	No change	No	UP (HCN) DP (Future)
H38	Changes in Geochemistry Due to Mining	No change	No	SO-C (HCN) SO-R (Future)
H39	Changes in Groundwater Flow Due to Explosions	No change	No	SO-C (HCN) SO-R (Future)
H40	Land Use Changes	No change	No	SO-R (HCN) SO-R (Future)
H41	Surface Disruptions	No change	No	UP (HCN) SO-C (Future)
H42	Damming of Streams or Rivers	No change	No	SO-C (HCN) SO-R (Future)
H43	Reservoirs	No change	No	SO-C (HCN) SO-R (Future)
H44	Irrigation	No change	No	SO-C (HCN) SO-R (Future)
H45	Lake Usage	No change	No	SO-R (HCN) SO-R (Future)
H46	Altered Soil or Surface Water Chemistry by Human Activities	No change	No	SO-C (HCN) SO-R (Future)
H47	Greenhouse Gas Effects	No change	No	SO-R (HCN) SO-R (Future)
H48	Acid Rain	No change	No	SO-R (HCN) SO-R (Future)
H49	Damage to the Ozone Layer	No change	No	SO-R (HCN) SO-R (Future)
H50	Coastal Water Use	No change	No	SO-R (HCN) SO-R (Future)
H51	Sea Water Use	No change	No	SO-R (HCN) SO-R (Future)
H52	Estuarine Water Use	No change	No	SO-R (HCN) SO-R (Future)

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
H53	Arable Farming	No change	No	SO-C (HCN) SO-R (Future)
H54	Ranching	No change	No	SO-C (HCN) SO-R (Future)
H55	Fish Farming	No change	No	SO-R (HCN) SO-R (Future)
H56	Demographic Change and Urban Development	No change	No	SO-R (HCN) SO-R (Future)
H57	Loss of Records	No change	No	NA (HCN) DP (Future)
H58	Solution Mining for Potash	Updated with information regarding solution mining activities in the region per EPA comment.	No	SO-R (HCN) SO-R (Future)
H59	Solution Mining for Other Resources	Updated with new information regarding brine wells in the region.	No	SO-C (HCN) SO-C (Future)
W1	Disposal Geometry	Update with new information regarding the abandonment of panel closures in the south end of the mine, correction of the northernmost panel closure dimensions, and additional shaft and associated drifts.	No	UP
W2	Waste Inventory	Updated to reflect the inventory data sources used for the CRA-2019 PA and per EPA comment.	No	UP
W3	Heterogeneity of Waste Forms	Updated to reflect the inventory data sources used for the CRA-2019 PA and per EPA comment.	No	DP
W4	Container Form	Updated to reflect the inventory data sources used for the CRA-2019 PA.	No	SO-C – Beneficial

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W5	Container Material Inventory	Updated to reflect the inventory data sources used for the CRA-2019 PA.	No	UP
W6	Shaft Seal Geometry	Updated to reflect new shaft.	No	UP
W7	Shaft Seal Physical Properties	No change	No	UP
W109	Panel Closure Geometry	Updated with new information regarding the abandonment of panel closures in the south end of repository, and correction of northernmost panel closure dimensions.	No	UP
W110	Panel Closure Physical Properties	Updated to reflect new material properties for different panel closure areas.	No	UP
W8	Shaft Seal Chemical Composition	Updated to reflect additional shaft.	No	SO-C Beneficial
W111	Panel Closure Chemical Composition	Updated screening argument with new information regarding steel bulkhead construction aide.	No	SO-C Beneficial
W9	Backfill Physical Properties	No change	No	SO–C
W10	Backfill Chemical Composition	No change	No	UP
W11	Post-Closure Monitoring	No change	No	SO-C
W12	Radionuclide Decay and In-Growth	No change	No	UP
W13	Heat from Radioactive Decay	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W14	Nuclear Criticality: Heat	Updated to reflect the inventory used for the CRA-2019 PA and new criticality analysis.	No	SO-P

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W15	Radiological Effects on Waste	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W16	Radiological Effects on Containers	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W17	Radiological Effects on Shaft Seals	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W112	Radionuclide Effects on Panel Closures	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W18	Disturbed Rock Zone (DRZ)	Updated to reference treatment of the DRZ near the ROM salt PCS.	No	UP
W19	Excavation-Induced Changes in Stress	Updated to reference treatment of the DRZ near the ROM salt PCS.	No	UP
W20	Salt Creep	Updated to reference treatment of the DRZ near the ROM salt PCS.	No	UP
W21	Changes in the Stress Field	Updated to reference treatment of the DRZ near the ROM salt PCS.	No	UP
W22	Roof Falls	Updated to reference additional drifts to new shaft.	No	UP
W23	Subsidence	No change	No	SO-C
W24	Large Scale Rock Fracturing	Updated to reference additional drifts to new shaft.	No	SO-P
W25	Disruption Due to Gas Effects	Updated per EPA comment.	No	UP
W26	Pressurization	Updated to reflect gas generation due to radiolysis of brine, the removal of sulfidation reactions, and refinement of the hydromagnesite conversion process.	No	UP

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W27	Gas Explosions	No change	No	UP
W28	Nuclear Explosions	Updated to reflect the inventory used for the CRA-2019 PA and per EPA comment.	No	SO-P
W29	Thermal Effects on Material Properties	Update to reflect the inventory used for the CRA-2019 PA, underground experiments, and EPA comments.	No	SO-C
W30	Thermally-Induced Stress Changes	Update to reflect the inventory used for the CRA-2019, underground experiments, and EPA comments.	No	SO-C
W31	Differing Thermal Expansion of Repository Components	Update to reflect the inventory used for the CRA-2019, underground experiments, and EPA comments.	No	SO-C
W72	Exothermic Reactions	Updated to reflect the inventory used for the CRA-2019, underground experiments, and EPA comments.	No	SO-C
W73	Concrete Hydration	Updated to reflect the inventory used for the CRA-2019, underground experiments, the additional shaft, and EPA comments.	No	SO-C
W32	Consolidation of Waste	No change	No	UP
W36	Consolidation of Shaft Seals	Updated to reflect additional shaft.	No	UP
W37	Mechanical Degradation of Shaft Seals	Updated to reflect additional shaft.	No	UP
W39	Underground Boreholes	No change	No	UP

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W113	Consolidation of Panel Closures	Updated per EPA comment.	No	UP
W114	Mechanical Degradation of Panel Closures	Updated screening argument per EPA comment. Update screening decision to reflect that ROM salt closures will not degrade. Updated screening decision to SO-P.	Yes	SO-P
W33	Movement of Containers	Updated to reference the inventory used for the CRA-2019 PA.	No	SO-C
W34	Container Integrity	No change	No	SO–C Beneficial
W35	Mechanical Effects of Backfill	No change	No	SO–C
W40	Brine Inflow	Updated to reflect new parameter distribution for PBRINE, and elimination of panel closures in south end of repository.	No	UP
W41	Wicking	No change	No	UP
W42	Fluid Flow Due to Gas Production	Updated to reflect new parameter distribution for PBRINE and the removal of two sulfidation reactions refinement of the hydromagnesite conversion process.	No	UP
W43	Convection	Updated to reflect the inventory used for the CRA-2019, underground experiments, and reference correction to mined volume in experimental area.	No	SO-C
W44	Degradation of Organic Material	Updated to reference new inventory used for CRA-2019 PA and EPA comment.	No	UP

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W45	Effects of Temperature on Microbial Gas Generation	Updated to reference new inventory used for CRA-2019 PA and EPA comment.	No	UP
W48	Effects of Biofilms on Microbial Gas Generation	Updated to reflect the inventory used for the CRA-2019.	No	UP
W46	Effects of Pressure on Microbial Gas Generation	No change	No	SO-C
W47	Effects of Radiation on Microbial Gas Generation	Updated to reflect the inventory used for the CRA-2019.	No	SO-C
W49	Gases from Metal Corrosion	Updated to reference new corrosion rates of steel and to reflect the inventory used for CRA-2019 PA.	No	UP
W51	Chemical Effects of Corrosion	Updated to reference new corrosion rates of steel and to reflect the inventory used for CRA-2019.	No	UP
W50	Galvanic Coupling (Within the Repository)	No change	No	SO-C
W52	Radiolysis of Brine	Updated with new analysis that demonstrates gas from radiolysis of brine no longer insignificant contributor to overall gas quantity.	Yes	UP
W53	Radiolysis of Cellulose	Screening argument updated to account for matrix depletion.	No	SO-C
W54	Helium Gas Production	Updated to reflect new inventory used for the CRA-2019 PA.	No	SO-C
W55	Radioactive Gases	Updated to reflect new inventory used for the CRA-2019 PA.	No	SO-C

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W56	Speciation	Reference made to new solubility calculations based on new inventory components.	No	UP in disposal rooms and Culebra. SO-C elsewhere, and SO-C Beneficial in cementitious seals
W57	Kinetics of Speciation	No change	No	SO-C
W58	Dissolution of Waste	No change	No	UP
W59	Precipitation of Secondary Minerals	No change	No	SO-C Beneficial
W60	Kinetics of Precipitation and Dissolution	No change	No	SO-C
W61	Actinide Sorption	No change	No	UP in the Culebra and Dewey Lake; SO-C—Beneficial in the disposal room, shaft seals, panel closures, and other geologic units.
W62	Kinetics of Sorption	No change	No	UP in the Culebra and Dewey Lake; SO-C—Beneficial in the disposal room, shaft seals, panel closures, and other geologic units.
W63	Changes in Sorptive Surfaces	No change	No	UP
W64	Effects of Metal Corrosion	No change	No	UP
W66	Reduction-Oxidation Kinetics	No change	No	UP
W65	Reduction-Oxidation Fronts	No change	No	SO-P
W67	Localized Reducing Zones	Updated to reflect gas generation from radiolysis.	No	SO-C
W68	Organic Complexation	Updated to reflect new solubility calculations for use in the CRA-2019 PA.	No	UP
W69	Organic Ligands	Updated to reflect new solubility calculations for use in the CRA-2019 PA.	No	UP
W71	Kinetics of Organic Complexation	No change	No	SO-C

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W70	Humic and Fulvic Acids	No change	No	UP
W74	Chemical Degradation of Shaft Seals	Update to reflect additional shaft.	No	UP
W76	Microbial Growth on Concrete	No change	No	UP
W115	Chemical Degradation of Panel Closures	Updated screening argument per EPA comment.	No	SO-P
W75	Chemical Degradation of Backfill	No change	No	SO-C
W77	Solute Transport	No change	No	UP
W78	Colloid Transport	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	No	UP
W79	Colloid Formation and Stability	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	No	UP
W80	Colloid Filtration	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	No	UP
W81	Colloid Sorption	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	No	UP
W82	Suspensions of Particles	No change	No	DP
W83	Rinse	No change	No	SO-C
W84	Cuttings	Updated to reflect new implementation in Panel 9.	No	DP
W85	Cavings	Updated with new waste shear strength data and implementation in Panel 9.	No	DP
W86	Spallings	Updated to reflect new implementation in Panel 9.	No	DP

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W87	Microbial Transport	Updated with reference to new colloidal actinide source term and colloidal actinide parameters.	No	UP
W88	Biofilms	No change	No	SO-C Beneficial
W89	Transport of Radioactive Gases	Updated to reflect the inventory used for the CRA-2019 PA.	No	SO-C
W90	Advection	No change	No	UP
W91	Diffusion	No change	No	UP
W92	Matrix Diffusion	No change	No	UP
W93	Soret Effect	Updated to reflect the inventory used for the CRA-2019.	No	SO-C
W94	Electrochemical Effects	No change	No	SO-C
W95	Galvanic Coupling (Outside the Repository)	No change	No	SO-P
W96	Electrophoresis	No change	No	SO-C
W97	Chemical Gradients	Updated to reference updated colloidal enhancement parameters.	No	SO-C
W98	Osmotic Processes	No change	No	SO-C
W99	Alpha Recoil	No change	No	SO-C
W100	Enhanced Diffusion	No change	No	SO-C
W101	Plant Uptake	No change	No	SO-R (for section 191.13) SO-C (for section 191.15)
W102	Animal Uptake	No change	No	SO-R (for section 191.13) SO-C (for section 191.15)
W103	Accumulation in Soils	No change	No	SO-C Beneficial (for section 191.13) SO-C (for section 191.15)

Table 1. Complete List of FEPs in the CRA-2019 SNL FEP Baseline (continued)

EPA FEP I.D.[a,b,c,d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W104	Ingestion	No change	No	SO-R SO-C (for section 191.15)
W105	Inhalation	No change	No	SO-R SO-C (for section 191.15)
W106	Irradiation	No change	No	SO-R SO-C (for section 191.15)
W107	Dermal Sorption	No change	No	SO-R SO-C (for section 191.15)
W108	Injection	No change	No	SO-R SO-C (for section 191.15)

[a] N = Natural FEP
[b] H = Human-induced event and process (EP)
[c] W = Waste- and Repository-induced FEP
[d] FEPs in this column that are not separated by rows represent FEPs that are similar in nature and are discussed and screened as a common group.

Source: CRA-2019, Appendix SCR, Table SCR-2.

2.0 SNL FEP Review for CRA-2019

SNL reviewed the Agency-approved 2014 FEP baseline on behalf of DOE in preparation for the 2019 CRA to determine if the baseline remained appropriate in consideration of new information that had become available since it was prepared. SNL's review was guided by SNL Specific Procedure SP 9-4, *Performing FEPs Baseline Impact Assessments for Planned and Unplanned Changes* (Kirkes 2016). In addition to reviewing the previous baseline, SNL reviewed related information published by EPA in Compliance Application Review Documents and TSDs supporting the Agency's 2014 recertification decision (EPA 2017b) as well as FEP assessments and PA model modifications made by SNL since 2014. SNL's analysis also evaluated new information from outside the WIPP PA program with an emphasis on information relating to human activities in the WIPP vicinity.

For the CRA-2019, SNL's reassessment of FEPs concluded that of the 245 FEPs considered, 161 had not changed and 84 needed to be updated with new information since the CRA-2014 (CRA-2019, Appendix SCR-2019, p. SCR-1). Of the 84 updated FEPs, the following four had their screening decisions changed.

- FEPs N26 *Density Effects on Groundwater Flow* and H36 *Borehole-Induced Geochemical Changes* (for units other than the Culebra), formerly screened out due to low consequence, were now screened out due to beneficial consequences.

- FEP W52 *Radiolysis of Brine,* formerly screened out due to low consequence, was screened in to undisturbed performance (UP) scenarios due to new analyses that demonstrated that radiolysis of brine is no longer an insignificant contributor to overall gas generation.
- FEP W114 *Mechanical Degradation of Panel Closures,* formerly accounted for in UP scenarios, was screened out due to low probability, as a result of the use of run-of-mine salt instead of concrete in panel closures.

2.1 Changes between CRA-2014 and CRA-2019 Performance Assessments

DOE's CRA-2014 PA is the most recent Agency-approved PA and was used by SNL as the basis for identifying relevant changes to the CRA-2019 PA. The changes to the CRA-2019 PA were identified by DOE (CRA-2019, Appendix PA-2019, Section PA-1.1) and are summarized below.

2.1.1 Waste Area Design Changes

The WIPP repository was closed in February 2014 following an accidental release of radionuclides that contaminated the south end of the underground repository waste area. Although the repository was later reopened on a limited basis, access to the contaminated areas was prohibited and routine maintenance of ground control could not be conducted. This resulted in unsafe conditions that led to a DOE decision to withdraw from and seal off the part of the waste area designated as Panel 9 (DOE 2016). With that change, the planned installation of run-of-mine (ROM) salt panel closures in Panels 3, 4, 5, and 6 would no longer be possible because access to these panels required access to Panel 9. Also, waste emplacement in Panel 9 would no longer be possible and DOE proposed a replacement for Panel 9 at an undesignated location within the underground repository. Because of these changes, in December 2017 DOE proposed modifying the methodology of the CRA-2019 PA by incorporating an Abandonment of Panel Closures in the South (APCS) approach. This approach is described in Zeitler et al. (2017) and is briefly described below. Upon review, the Agency agreed with incorporating this approach in the deferred CRA-2019 PA (Veal 2017).

The APCS approach was designed by SNL to conservatively overestimate repository releases while accounting for the abandonment of Panel 9 and the lack of ROM salt panel closures in the access drifts to the four southernmost waste panels. The lack of panel closures was modeled by ignoring salt creep and changing the material properties for the now open access drifts to be the same as the high porosity and permeability "open drift" properties used for the WIPP Operations and Experimental (OPS/EXP) areas. The abandoned Panel 9 continued to be modeled as waste-filled, serving as a surrogate for the replacement Panel 9. In addition, the "neighbors" relationships among waste panels was redefined such that the isolation afforded by single ROM salt panel closures, including the closures between Panels 9 and 10, was ignored. This convention allowed brine and gas to flow relatively unimpeded between certain adjacent panels. The rationale for these changes is presented in Zeitler et al. (2017) and is further discussed in EPA's TSD *Review of the APCS Approach to Analyzing WIPP Repository Performance in the CRA-2019 Performance Assessment* (Docket ID No. EPA-HQ-OAR-2019-0534).

2.1.2 Additional Shaft and Associated Drifts

In addition to the south end of the underground repository waste area, the accidental radionuclide release mentioned in Section 2.1.1 also contaminated the exhaust ventilation shaft. As a result, DOE is planning a modified ventilation system that will provide sufficient airflow for future disposal operations (Shrader 2017). The primary components of this system are a new shaft in the north end of the repository and the associated drifts needed to connect the new shaft to the repository. A detailed review of the new shaft and connecting drifts is presented in EPA's TSD "*Review of DOE Planned Change Notice for a Fifth Shaft at the WIPP Repository*" (Docket ID No. EPA-HQ-OAR-2019-0534).

2.1.3 Incorporation of Brine Radiolysis

Gas generation from radiolysis of brine in the WIPP repository results primarily from the decay of americium and plutonium isotopes. Gas generation is important to repository performance because elevated gas pressure is a primary driver of all but the cuttings and cavings release pathways. The increased mass of plutonium projected for disposal in the CRA-2019 waste inventory (Kicker 2019) prompted a reevaluation of the significance of radiolysis to repository performance (Day 2019). Brine radiolysis was added to the gas generation process model in response to this evaluation and to a confirmation of the increased importance of this process to repository performance through the FEP screening process (Kirkes 2019).

2.1.4 Refinement of the Probability of Encountering Pressurized Brine

The WIPP PA parameter GLOBAL:PBRINE (hereafter called PBRINE) is used to specify the probability that a drilling intrusion into the waste area of the repository encounters a region of pressurized brine in the Castile Formation below the repository. A new distribution for this uncertain parameter was developed by SNL (Kirchner et al. 2012) and was used in the CRA-2014 PA in place of the previous distribution mandated by EPA in 1998 (Peake 1998). SNL's distribution was based solely on drilling data and did not consider relevant time-domain electromagnetic (TDEM) geophysical data and hydrogeologic field investigations of known brine reservoirs. The Agency since created a revised distribution for the PBRINE parameter based on a reexamination of the original TDEM and field data, and directed its use in the CRA-2019 PA (EPA 2017c; Veal 2017).

2.1.5 Refinement of the Corrosion Rates of Steel

The interaction of steel in the WIPP with repository brines results in the generation of hydrogen gas from anoxic corrosion. The brine-inundated corrosion rate (STEEL:CORRMCO2) and the humid condition corrosion rate (STEEL:HUMCORR) were updated for the CRA-2019 PA. These changes were based on experimental results from Roselle (2013), the potential for enhanced corrosion at elevated pressures, and the bounding CO_2 level (5 ppm) expected in the repository (Zeitler 2018).

2.1.6 Refinement of the Effective Shear Strength of WIPP Waste

WIPP PA includes scenarios in which human intrusion results in boreholes intersecting the waste area of the repository. During an intrusion, drilling mud flowing up the borehole will apply a hydrodynamic shear stress on the waste in the borehole wall. Erosion of the waste material can occur if the shear stress is high enough, resulting in radioactive waste being carried up the borehole with the drilling mud and released to the accessible environment. The WIPP PA parameter BOREHOLE:TAUFAIL (hereafter called TAUFAIL) is used to represent the effective shear strength for the erosion of WIPP waste. For the CRA-2014 PA, experimental results from Herrick et al. (2012) were used to determine an updated parameter distribution for TAUFAIL (Herrick and Kirchner 2013). Subsequent to the submittal of the CRA-2014, EPA requested DOE to reduce the lower bound of the TAUFAIL distribution to equal the lowest measured value of the subset of the Herrick data included in that distribution (EPA 2017d). DOE agreed to use the revised lower bound in the CRA-2019 PA.

2.1.7 Refinement of Colloid Enhancement Parameters

Changes were made to colloid enhancement parameters based on new laboratory and literature data since the CRA-2014 PA. These parameters are used to calculate mobilized radionuclide concentrations (Reed et al. 2019; Mariner 2019). In addition, the basis for the CAPMIC (maximum concentration of actinides on microbial colloids) parameterization changed for the CRA-2014 PA from a toxicity to a biomass approach (Reed, et al. 2013), but the PANEL code was not correspondingly updated. For the CRA-2019 PA, the PANEL code has been updated and there is now consistency between the parameterization of the CAPMIC property and PA calculations (Sarathi 2019).

2.1.8 Refinement of Hydromagnesite Conversion Rate

The reaction of hydromagnesite to form magnesite was included along with an associated reaction rate in the CRA-2014 PA. Subsequent to the submittal of the CRA-2014, EPA requested that DOE change the uncertainty distribution for the reaction rate and revise its range to account for a specified range of rates, including the possibility of no conversion to magnesite via a lower rate bound of zero (U.S. EPA 2017e). DOE accepted these changes and applied them in the CRA-2019 PA (Zeitler 2019).

2.1.9 Removal of Iron Sulfidation Reactions

Iron and iron hydroxide sulfidation reactions were included as part of the repository brine and gas production/consumption calculations in the CRA-2014 PA. Subsequent to the submittal of the CRA-2014, EPA requested that DOE remove these chemical reactions from WIPP PA by setting the appropriate stoichiometric coefficients to zero (EPA 2017e; Zeitler 2019). DOE agreed to these changes in the CRA-2019 PA.

2.1.10 Correction to Length of Northernmost Panel Closure Representation

Three separate panel closure areas are represented in the BRAGFLO Salado Flow model: the “northernmost” panel closure area between the Operations area and the North Rest-of-the-Repository (NROR), the “middle” panel closure area between the NROR and the South Rest-of-

the-Repository (SROR), and the "southernmost" panel closure area between the SROR and the Waste Panel. As part of the DOE/EPA completeness determination discussions for CRA-2014, the northernmost panel closure in the BRAGFLO grid was identified by the Agency as representing the length of one set of panel closures instead of the two sets of closures included in the repository design. DOE corrected this error by doubling the length of the northernmost panel closure area in the BRAGFLO grid for the CRA-2019 PA. The impact of this change on the pressures and brine saturations in the waste areas was found to be negligible (Zeitler 2015).

2.1.11 Updates in Drilling Rate and Plugging Pattern Parameters

EPA regulations (40 CFR 194.33) require that deep borehole drilling rates and plugging pattern frequencies be updated with current field data for each WIPP recertification. The data supporting these updates are developed by DOE through annual surveys of drilling and plugging activities in the Delaware Basin as documented in annual reports. Survey results through September 2018 were used as the basis for the updates in the CRA-2019 PA and are documented in the 2018 Delaware Basin Monitoring Annual Report (DBMAR) (DOE 2018). In addition to updating the rates and frequencies, DOE also changed the methodology for determining the plugging pattern frequencies by analyzing plugging practices of abandoned boreholes over a smaller area and therefore using a smaller database than previously used. Both the drilling rate and plugging pattern frequency parameters have changed substantially since the CRA-2014 PA due to a combination of increased exploratory drilling for hydrocarbon resources in the Delaware Basin and the change in plugging pattern methodology. Because these changes are potentially impactful on PA results, they have been separately evaluated by the Agency in the TSD "*Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment*" (Docket ID No. EPA-HQ-OAR-2019-0534).

2.1.12 Updates to WIPP Waste Inventory Parameters

In addition to borehole drilling and plugging practices, the current and projected WIPP waste inventory is also updated for each recertification. The waste inventory used in the CRA-2019 PA is described in the 2018 Performance Assessment Inventory Report (PAIR-2018) (Van Soest 2018). This report presents inventory information collected through the cutoff date of December 31, 2017.

2.1.13 Updates to Radionuclide Solubilities

The solubilities of actinide elements are influenced by the chemical components of the waste and by the disposal environment. Updated information on the chemical components in the waste was provided in the PAIR-2018 (Van Soest 2018). Based upon this information and an updated thermodynamic database (Domski 2019a), the parameters used to represent actinide solubilities were updated in the CRA-2019 PA (Domski and Sisk-Scott 2019). The updates included correlating dissolved actinide concentrations with waste panel brine volumes (CRA-2019, Appendix GEOCHEM, Section 1.2.5.4; Domski and Sisk-Scott 2019). Additionally, uncertainty ranges and probability distributions for actinide solubilities were recalculated using the updated thermodynamic database (Domski 2019c). Baseline solubility parameters for the CRA-2019 PA are summarized in Domski (2019b).

2.1.14 Update to BH_OPEN:RELP_MOD Parameter

Errors in the BRAGFLO code related to the calculation of capillary pressure were discovered and corrected by DOE, as detailed in the software problem report (SPR) 18-002 (Day 2018). These errors were determined to have an insignificant effect on repository performance results. One of the corrections prompted a change in the relative permeability model used when simulating flow in an open borehole (parameter BH_OPEN:RELP_MOD). The relative permeability model number was changed from 5 (the value used in the CRA-2014 PA) to 11 (for the CRA-2019 PA). This change was made because the code correction introduced capillary effects into RELP_MOD = 5 that resulted in a positive capillary pressure within the open borehole, which is physically unrealistic. The use of RELP_MOD = 11 for the BH_OPEN material assumes no capillary effects and is consistent with the relative permeability and (zero) capillary pressure implemented for other "open" repository areas such as the OPS/EXP Areas.

2.1.15 New Materials to Define Properties in the DRZs Surrounding Operations, Experimental, and Panel Closure Areas

As part of its review of the CRA-2014, the Agency directed multiple sensitivity studies that investigated the impacts of parameter changes to the OPS/EXP and panel closure areas and their associated disturbed-rock zones (DRZs). To facilitate those analyses, DOE introduced new material names for the DRZs to provide flexibility in specifying material properties independently across areas for which material properties in the CRA-2014 PA were identical. DOE chose to retain this flexibility by keeping these new material names in the CRA-2019 PA. These new materials represented the DRZs for the OPS/EXP Areas for times -5 to 0 years (DRZ_OE_0) and 0 to 10,000 years (DRZ_OE_1), the DRZs for active panel closures for times -5 to 0 years (DRZ_PC_0) and 0 to 10,000 years (DRZ_PC_1), and the -5 to 0 year startup material for the active panel closures (CAVITY_5). Although the material names have changed, the parameter values for these areas of the BRAGFLO grid have not changed since the CRA-2014 PA.

2.1.16 Hardware and Computational Code Updates

Calculations for the CRA-2014 PA were performed on the WIPP PA Alpha Cluster, which consisted of HP AlphaServer hardware running the OpenVMS operating system (Long 2013). WIPP PA codes were later migrated to the WIPP PA Solaris Cluster, which consists of Intel hardware running the Solaris operating system (Kirchner et al. 2012; 2014; 2015). The CRA-2019 PA was run on the WIPP PA Solaris Cluster. The code migration and subsequent updates did not involve any changes to the FEPs baseline or screening arguments and is included here as a change that occurred since the CRA-2014 PA for completeness.

2.2 SNL FEP Baseline Review Results

The results of SNL's FEP review for the CRA-2019 PA are documented in Kirkes (2019). In compiling the results of the review, SNL distinguished between model changes based on new information, which are reflected in modifications to the FEP baseline, and model changes to

improve modeling efficiency or realism, which may not be based on new information and may therefore not be reflected in modifications to the FEP baseline. SNL's review concluded that the 245 FEPs in the 2014 baseline adequately addressed the types of features, events, and processes relevant to the CRA-2019 PA. Therefore, although some screening arguments were updated and some screening classifications were changed, SNL concluded that no FEPs in the 2014 baseline needed to be combined and none needed to be added. As previously noted, of the 245 FEPs in the new baseline for the CRA-2019 PA, 161 FEPs were unchanged from the CRA-2014 PA and 84 FEPs were updated by SNL with new information. The FEPs identified by SNL as being updated are listed in Table 2 along with a summary statement of SNL's reported change and EPA comments on that change. Additional background information is provided for some Agency comments help explain their context. FEPs that were not considered by SNL to have changed but were identified by EPA as meriting an updated evaluation are presented in Table 3. Yellow highlighted blocks in Tables 2 and 3 indicate EPA concerns that may require additional analysis and were identified by EPA as deserving special attention by DOE. Further discussion of EPA's evaluation of SNL's CRA-2019 FEP review is provided in Section 3 of this TSD.

Table 2. Changes in DOE CRA-2019 FEP Baseline

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
N2 Brine Reservoirs	Updated by referencing new PA parameter GLOBAL:PBRINE	Screening argument accepted.	Accepted
N12 Seismic Activity	Updated with new seismic data	Screening argument accepted. *EPA expressed a concern in Completeness Comment CC3-SCR-5b that seismic events could trigger rock falls that could impact repository performance during the first several hundred years of the postclosure period before creep closure is complete. The EPA acknowledges that the occurrence of rock falls is uncertain even in the absence of seismic events and accepts the DOE response that a seismically induced rockfall is unlikely because of the lack of significant seismic events at or near the WIPP site.* *Additional information regarding the Agency's concern is documented in EPA Completeness Comment CC5-SCR-5b in Appendix A.*	Accepted
N26 Density Effects on Groundwater Flow	Screening decision changed from SO-C to SO-C – Beneficial	Screening argument accepted.	Accepted
N71 Microbes	Edited for clarity and updated experimental references	*The DOE screening argument for this FEP concludes that microbes do not migrate with the advective flow in the Culebra because they are rapidly filtered out. EPA's concerns with this FEP screening argument are twofold. First, the information on microbe sizes was limited and did not account for the variations seen in nature, and second, no information was provided supporting the conclusion that physical filtering in the Culebra would limit microbe migration to the extent that it could be ignored in WIPP PA. These concerns were expressed to DOE in the Agency's Completeness Comment CC3-SCR-1.* *DOE's response to the first of these concerns provided an abundance of size data that adequately addressed that concern. EPA requests that a summary of these data be included in the screening argument for this FEP in the CRA-2024 submittal.* *DOE's response to the second concern indicated that the conclusion of substantial filtration rested primarily on the results of column tests on crushed Culebra dolomite. The Agency considers DOE's conclusion to be poorly supported by such tests because crushed dolomite simulates a*	Needs further support and should be revised for CRA-2024. Potentially Increased Significance (see Section 3.0)

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		porous medium and microbe transport through porous media does not replicate the advective flow and transport that would occur in the fractures and vugs in the conceptual model of the actual Culebra strata. In a single test performed on actual Culebra core, the movement of microbes was reduced but not eliminated. Insufficient information was presented to support DOE's conclusion that the movement that did occur was of no consequence to WIPP PA or that the core sample itself was representative of the lower transmissive zone of the Culebra. Although the Agency does not expect this concern to have a significant effect on repository performance because Culebra releases are very low, EPA expects DOE to review the screening argument for this FEP for the CRA-2024 and either screen it in into WIPP PA or provide an adequate justification for continuing to screen it out. *Further discussions of EPA's concerns and DOE's responses for this FEP are presented under Completeness Comment CC3-SCR-1 in Appendix A.*	
H1 Oil and Gas Exploration	Updated with new drilling rate	Screening argument accepted. *The screening argument relies heavily on information from the 1980s and should be updated to better reflect current practices such as horizontal drilling and multi-stage hydraulic fracturing. For example, the Delaware Basin is now considered to have "multiple stacked plays" of hydrocarbons in the WIPP area that include the Bone Springs, Wolfcamp, and Atoka in addition to the Morrow and Delaware Mountain Group mentioned in the current argument. EPA has additional concerns with the drilling rate calculation related to this FEP as documented in the Agency's Technical Support Document* "Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment" *(Docket ID No. EPA-HQ-OAR-2019-0534).*	Accepted
H4 Oil and Gas Exploitation	Updated with new drilling rate	Screening argument accepted. *However, EPA has concerns with the drilling rate calculation related to this FEP as documented in the Agency's Technical Support Document* "Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment" *(Docket ID No. EPA-HQ-OAR-2019-0534).*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
H3 Water Resources Exploration	Updated with most recent monitoring information	Screening argument accepted.	Accepted
H5 Groundwater Exploitation H26 Groundwater Extraction	Updated with most recent monitoring information	*The combined screening argument for H3 and H5 primarily focuses on the effects of shallow drilling for groundwater and not on the effects of groundwater exploitation. FEP H26 addresses groundwater extraction. The difference between "exploitation" and "extraction" should be explained and the combined screening argument for H3 and H5 should be expanded to address groundwater exploitation consistent with the provided definition. This EPA concern is essentially for clarification and is unlikely to affect repository performance.*	Clarification needed for CRA-2024
H21 Drilling Fluid Flow	Updated to justify the exclusion of northern experimental area of mined area from intrusion.	Screening argument accepted. *In the CRA-2014 completeness review, EPA stated that the screening argument for this FEP should be supplemented with a discussion of boreholes that could intersect the non-waste regions of the repository. The supplemental information was added to the CRA-2019 screening argument as requested.*	Accepted
H22 Drilling Fluid Loss	Updated to justify the exclusion of northern experimental area of mined area from intrusion.	Screening argument accepted. *The comments on H21 also apply to H22.*	Accepted
H23 Blowouts	Updated with new parameter GLOBAL:PBRINE	Screening argument accepted. *Use of a new uncertainty distribution for the parameter GLOBAL:PBRINE was mandated by EPA following its review of CRA-2014.*	Accepted
H28 Enhanced Oil and Gas Production - OB	Updated per EPA comment regarding enhanced oil and gas production techniques in the Delaware Basin	Screening argument accepted. *In the CRA-2014 completeness review, EPA stated that the screening argument for this FEP should be supplemented to address whether enhanced oil and gas production techniques are being used in the Delaware Basin. The supplemental information was added to the CRA-2019 screening argument as requested.*	Accepted
H31 Natural Borehole Fluid Flow	Updated to reflect BRAGFLO corrections for open borehole parameters and to reflect new plugging probabilities.	*The screening argument for this FEP includes a new method for calculating borehole plugging frequencies that has not been accepted by EPA because it is not adequately supported by regulatory considerations or by current practice. EPA expects DOE to revert to the previously-approved methodology for calculating plugging pattern probabilities in the CRA-2024 PA, or otherwise propose alternative methods that may be*	Inadequate justification for changed plugging probability

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		approved by EPA prior to that time , and to modify the screening argument for this FEP accordingly. The impact of this concern on WIPP performance was evaluated by the Agency in a sensitivity analysis and the results were found to remain well below regulatory limits. *A detailed review of the new method and the Agency's concerns and conclusions are presented in the Agency's Technical Support Document* "Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment" *(Docket ID No. EPA-HQ-OAR-2019-0534).*	method; deserves special attention (see Section 3.0)
H32 Waste-Induced Borehole Flow	Updated to reflect new plugging probabilities	*The comments on H31 also apply to H32.*	See previous
H36 Borehole-Induced Geochemical Changes	Screening decision changed from SO-C to SO-C – Beneficial for units other than the Culebra	Screening argument accepted.	Accepted
H58 Solution Mining for Potash	Updated with information regarding solution mining activities in the region per EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA noted that renewed activity at the previously abandoned workings of the Eddy Potash Mine provided an opportunity for updating the technical and economic constraints described in the screening argument for this FEP. In response, DOE added supplemental information to the CRA-2019 screening argument on the possible consequences of solution mining near the WIPP but noted that this FEP was screened out on a regulatory rather than a technical basis because the activity at the Eddy Potash mine is outside the Delaware Basin.*	Accepted
H59 Solution Mining for Other Resources	Updated with new information regarding brine wells in the region	Screening argument accepted.	Accepted
W1 Disposal Geometry	Updated with new information regarding the abandonment of panel closures in the south end of the mine, correction of the northernmost panel closure dimensions, and additional shaft and associated drifts.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to provide evidence that the modeled excavated volume is the expected mined volume of the underground workings at the time of closure. EPA made this request because it was not clear whether the modeled volume included all planned excavations for the SDI/SDDI tests. In response, DOE stated that this type of information is best left in the supporting documentation, rather than within the screening document, and referenced DOE's response to EPA Comment 1-23-7 (Franco 2015).*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		That response included a calculation of the repository volume including the excavations for the planned tests as of the data cut-off date of December 31, 2012 for the CRA-2014 PA. EPA accepted this response but stated that future screening arguments for this FEP should include a reference to supporting documentation where the basis for the modeled excavated volume is described and justified as being the expected volume at the time of closure. The requested reference was included in the Appendix SCR-2019 screening argument for this FEP. *Franco, J.R. 2015. Letter to J. Edwards (Subject: Response to Environmental Protection Agency Letter Dated December 17, 2014 Regarding the 2014 Compliance Recertification Application). March 18, 2015. U.S. Department of Energy, Carlsbad Field Office, Carlsbad, NM.*	
W2 Waste Inventory	Updated to reflect the inventory data sources used for the CRA-2019 PA and per EPA comment.	Screening argument accepted.	Accepted
W3 Heterogeneity of Waste Forms	Updated to reflect the inventory data sources used for the CRA-2019 PA and per EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA stated that the screening argument citation of the CCA as the source of information on the heterogeneity of waste forms ignores changes that have occurred in the past 15 years, including super-compacted waste, mingling RH waste in shielded containers with CH waste, and potentially ignitable nitrate salt waste. EPA stated that the continued reliance on the CCA as an information source should be reviewed and updated. The screening argument was updated in the CRA-2019 to emphasize the waste homogeneity assumptions in PA. The different container types currently in use were identified in supplemental information provided in the screening argument for FEP W4* Container Form.	Accepted
W4 Container Form	Updated to reflect the inventory data sources used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W5 Container Material Inventory	Updated to reflect the inventory data sources used for the CRA-2019 PA.	*In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with an explanation of the implementation in PA of the material inventory of shielded containers containing RH waste. This comment was directed at treatment of the extensive mass of lead that could be introduced into the repository in such containers. The screening argument was updated by DOE in the*	Should be revised for CRA-2024 with new information

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		CRA-2019 as requested to cite the updated material inventory, to acknowledge the use of shielded containers, and to cite an analysis of the impacts of such containers on WIPP performance. However, DOE analysis was limited to corrosion rate data from fully submerged lead coupons because of uncertainty in partially submerged corrosion rates even though the variations seen in the experiments with partially submerged coupons are accounted for in the investigator's analysis of results. The investigator's treatment of uncertainty was reviewed by EPA and found to be adequate. *EPA therefore requested DOE to perform additional calculations using a mean lead corrosion rate provided by the Agency based on both partially and fully submerged coupons and on reasonable assumptions about the total lead surface area provided by DOE. The results supported the conclusion that lead corrosion would be an insignificant contributor to gas generation in the WIPP repository. EPA therefore concurs with DOE's conclusion that gases generated from corrosion of the lead inventory can continue to be omitted from performance calculations. EPA expects the results of these calculations to be included in the screening argument for this FEP in the CRA-2024.* *Additional information regarding the Agency's concerns is documented in EPA Completeness Comment CC5-SCR-9 in Appendix A. This same concern also affects W49 and W51.*	
W6 Shaft Seal Geometry	Updated to reflect new shaft.	Screening argument accepted.	Accepted
W8 Shaft Seal Chemical Composition	Updated to reflect additional shaft.	*Calcium ions, hydroxide ions, and isosaccharinic acid resulting from highly alkaline conditions could increase the solubilities of +III and +IV actinides. In Completeness Comment CC5-SCR-7 the Agency requested DOE to explain how these effects were considered in concluding that high pH effects of the cementitious materials in the shaft seals will lead to reduced radionuclide concentrations and were therefore beneficial to repository performance. DOE responded that the effects of cementitious material in repository shaft seals will not be significant because of the small volume of brine flowing through the seals, that chemical conditions at the WIPP are not cement-dominated because the presence of MgO greatly minimizes pH excursions, and that degradation of cellulosic*	Screening arguments do not adequately support screening decision and should be revised for CRA-2024

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		materials is not predicted to be extensive at the WIPP. The DOE response supported a screening conclusion of low consequence but did not support a conclusion of beneficial. The DOE's screening arguments for these FEPs should be reworded accordingly. *Additional information regarding the Agency's concerns is documented in EPA Completeness Comment CC5-SCR-7 in Appendix A. This same concern also affects W56.*	
W109 Panel Closure Geometry	Updated with new information regarding the abandonment of panel closures in the south end of repository, and correction of northernmost panel closure dimensions.	Screening argument accepted.	Accepted
W110 Panel Closure Physical Properties	Updated to reflect new material properties for different panel closure areas.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a description of the as-emplaced physical properties of the ROM salt to be used in the panel closures because in situ testing of the salt had been completed. The screening argument was updated in the CRA-2019 as requested to cite descriptions of those physical properties as modeled in PA.*	Accepted
W111 Panel Closure Chemical Composition	Updated screening argument with new information regarding steel bulkhead construction aide.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a description of the chemical composition of the steel bulkheads that are part of the panel closure design. The screening argument was updated in the CRA-2019 as requested to identify the use and chemical composition of the bulkheads.*	Accepted
W13 Heat from Radioactive Decay	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W14 Nuclear Criticality: Heat	Updated to reflect the inventory used for the CRA-2019 PA and new criticality analysis.	Screening argument accepted. *See discussion for W28.*	Accepted
W15 Radiological Effects on Waste	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W16 Radiological Effects on Containers	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
W17 Radiological Effects on Shaft Seals	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W112 Radionuclide Effects on Panel Closures	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W18 Disturbed Rock Zone (DRZ)	Updated to reference treatment of the DRZ near the ROM salt PCS.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to update the screening argument with a description of how the DRZ is accounted for in PA, noting that its treatment around the ROMPCS is different from its treatment in other parts of the underground excavations. The screening argument was updated as requested and supplemented with citations to other documents for more detailed information.*	Accepted
W19 Excavation-Induced Changes in Stress	Updated to reference treatment of the DRZ near the ROM salt PCS.	Screening argument accepted. *The comments on W18 also apply to W19.*	Accepted
W20 Salt Creep	Updated to reference treatment of the DRZ near the ROM salt PCS.	Screening argument accepted. *The comments on W18 also apply to W20.*	Accepted
W21 Changes in the Stress	Updated to reference treatment of the DRZ near the ROM salt PCS.	Screening argument accepted. *The comments on W18 also apply to W21.*	Accepted
W22 Roof Falls	Updated to reference additional drifts to new shaft.	Screening argument accepted as revised. *The screening argument limits the impact of roof falls to the DRZ and does not address the impact of roof falls into open rooms that are not filled with waste. Repository design changes since the CCA now anticipate that large portions of the Waste Area will be closed as open rooms subject to roof fall. EPA agrees with the screening statement that "In the long term, the effects of roof falls in the repository are likely to be minor because salt creep will reduce the void space and the potential for roof falls as well as promote healing of any roof material that has fallen into the rooms." However, this conceptual model of the impact of roof falls into open rooms has not been accounted for in WIPP PA. This concern was expressed to DOE in the Agency's Completeness Comment CC3-SCR-2. The DOE response to CC3-SCR-2 was satisfactory. DOE provided a supplemental text and committed to include it in the CRA-2019 errata. The Agency also expects DOE to include this supplemental text in the CRA-2024 submittal.*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
W23 Subsidence	Updated to reference additional drifts to new shaft.	*This FEP addresses the effect of subsidence due to repository excavations and due to possible future mining on the Culebra release pathway. EPA's concerns with this FEP's screening argument are twofold. First, the argument is based on the 1994 repository design and has not been updated since, particularly with regard to the large increase in the volume of open areas due to the abandonment of Panel 9. Second, the argument does not explain or justify the difference in treatment in WIPP PA between subsidence due to repository excavations and subsidence due to potash mining. These concerns were expressed to DOE in the Agency's Completeness Comment CC3-SCR-3.* *EPA found DOE's response to the first concern to be satisfactory. DOE agreed to expand the discussion of repository design changes in the CRA-2024 submittal and provided information adequately supporting its conclusion that the effect of current changes on Culebra hydrology would be small.* *EPA found DOE's response to the second concern to be inadequate. The effects of subsidence on the Culebra due to mining are treated in WIPP PA as multipliers of the base-case Culebra transmissivities. This is because those transmissivities are based on geohydrologic field data that do not intrinsically incorporate subsidence due to mining because the mining has not yet occurred. EPA notes that complete subsidence due to repository excavations has also not occurred yet it is argued by DOE to be intrinsically incorporated in the base-case field data. In addition, the effects of future mining and related subsidence are uncertain to occur while the effects of subsidence due to repository excavations are certain to occur. Subsidence due to repository excavations is estimated in DOE's screening argument to potentially increase the horizontal transmissivity of the Culebra by an order of magnitude. With the retardation currently expected in the Culebra, releases through the Culebra are a minor contributor to releases so this issue has limited consequence in the current modeling.* *EPA expects that, for the CRA-2024, the screening argument for FEP W23 will be updated to either screen in an increase Culebra transmissivity in WIPP PA by a technically justified amount within the area affected by subsidence due to WIPP excavations, or to provide a*	Partially adequate, needs updating and additional analysis; deserves special attention. (see Section 3.0)

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		demonstration that such an increase would have a negligible impact on the Culebra release pathway and can continue to be screened out. Further discussions of EPA's concerns and DOE's responses are presented under Completeness Comment CC3-SCR-3 in Appendix A. With the retardation currently expected in the Culebra, releases through the Culebra are a minor contributor to releases so this issue has limited consequence in the current modeling.	
W24 Large Scale Rock Fracturing	Updated to reference additional drifts to new shaft.	Screening argument accepted.	Accepted
W25 Disruptions Due to Gas Effects	Updated per EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of the potential for high waste panel gas pressures to delay consolidation of the ROM salt panel closures, thereby maintaining a higher permeability in the closures for a longer period of time. The screening argument was updated in the CRA-2019 as requested, with the statement:* "Gas pressurization effects are not expected to affect consolidation of the ROM salt PCS because physical (creep) closure and complete consolidation are expected to occur before significant gas pressures can develop."	Accepted
W26 Pressurization	Updated to reflect gas generation due to radiolysis of brine, the removal of sulfidation reactions, and refinement of the hydromagnesite conversion process.	Screening argument accepted. *The comments on W25 also apply to W26.*	Accepted
W28 Nuclear Explosions	Updated to reflect the inventory used for the CRA-2019 PA and per EPA comment.	Screening argument accepted. *This FEP was screened out by DOE on the basis of low probability. In the CRA-2014 completeness review, the Agency requested DOE to provide additional information on the quantities of fissile radionuclides in the inventory. DOE responded by stating that the FEP screening was based on the lack of a rapid compression mechanism rather than the overall inventory.* *In addition, DOE's CRA-2019 screening argument cites a numerical analysis of the effects of compression due to roof falls on nuclear criticality (Reedlunn and Bean 2019). The analyses predicted almost negligible container deformation and rearrangement from a roof fall for*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		7-packs of 6-inch and 12-inch pipe overpack containers stacked three-high in a waste panel with a resulting low compression and a low probability of criticality. However, the fall distance would be greater and the dynamic impact and subsequent rapid compression would be more severe if a roof fall occurred when only a single lift of containers had been emplaced. EPA considers that all credible scenarios should be evaluated when screening this FEP. The Agency's comments on W28 also apply to W14. This concern was expressed to DOE in the Agency's Completeness Comment CC3-SCR-4. *In response to the Agency's completeness comment, DOE stated that a nuclear explosion could not occur even if a roof fall occurred over a single lift of waste containers because the compressive forces would not be high enough or concentrated enough to create the necessary compaction. In addition, DOE has committed to update this screening argument for the CRA-2024. EPA therefore finds this response to be satisfactory. Further discussions of EPA's concerns and DOE's responses are presented under Completeness Comment CC3-SCR-4 in Appendix A.* *Reedlunn, B., and J. Bean. 2019. Simulations of Pipe Overpack Container Compaction at the Waste Isolation Pilot Plant. October 2019. Albuquerque, NM: Sandia National Laboratories. SAND2019-12111.*	
W29 Thermal Effects on Material Properties	Updated to reflect the inventory used for the CRA-2019 PA, underground experiments, and EPA comments.	Screening argument accepted. *EPA CRA-2014 comments were directed at W72 and W73, which are considered together with W29 in Appendix SCR-2019.*	Accepted
W30 Thermally-Induced Stress Changes	Updated to reflect the inventory used for the CRA-2019 PA, underground experiments, and EPA comments.	Screening argument accepted. *EPA CRA-2014 comments were directed at W72 and W73, which are considered together with W30 in Appendix SCR-2019.*	Accepted
W31 Differing Thermal Expansion of Repository Components	Updated to reflect the inventory used for the CRA-2019 PA, underground experiments, and EPA comments.	Screening argument accepted. *EPA CRA-2014 comments were directed at W72 and W73, which are considered together with W31 in Appendix SCR-2019.*	Accepted
W72 Exothermic Reactions	Updated to reflect the inventory used for the CRA-2019 PA, underground experiments, and EPA comments.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to update the screening argument with a discussion of the exothermic reaction that resulted in a 2014 accidental radiological release within the repository.*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		In response, DOE added the requested discussion to Appendix SCR-2014 and concluded that the reaction was not a normally anticipated event, that safeguards would be implemented to preclude its repetition, and that it had no effect on postclosure regulatory compliance. DOE omitted the requested discussion from Appendix SCR-2019 but clarified the screening argument to emphasize that all expected, long-term exothermic reactions were addressed.	
W73 Concrete Hydration	Updated to reflect the inventory used for the CRA-2019, underground experiments, the additional shaft, and EPA comments.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of the impact on PA of removing the Option D concrete monolith panel closures from the repository design and installing no additional explosion walls in the repository. In response, DOE modified the screening argument to state that the overall mass of concrete emplaced within the repository and the associated heat generated by its hydration will be reduced because of these changes, and that any increase in temperature generated by hydration of the remaining constructed elements of repository closure, such as shaft seals, will have largely abated by the time AICs are assumed to no longer prevent drilling into the repository.*	Accepted
W36 Consolidation of Shaft Seals	Updated to reflect additional shaft.	Screening argument accepted.	Accepted
W37 Mechanical Degradation of Shaft Seals	Updated to reflect additional shaft.	Screening argument accepted.	Accepted
W113 Consolidation of Panel Closures	Updated screening argument with new information regarding panel closure composition	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of consolidation specific to the ROM salt in the ROMPCS. EPA indicated that such a discussion can be found in Camphouse et al. (2012). DOE added the supplemental information to the screening argument as requested.*	Accepted
W114 Mechanical Degradation of Panel Closures	Updated screening argument per EPA comment. Update screening decision to reflect that ROM salt closures will not degrade. Updated screening decision to SO-P.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to acknowledge the presence of steel bulkheads as part of the panel closure system design. DOE responded by stating that the function of the bulkheads is to support construction of the ROM salt closures and that*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		they have no postclosure performance function. Although DOE did not acknowledge the presence of bulkheads in W114, the presence of bulkheads was acknowledged in W111.	
W33 Movement of Containers	Updated to reference the inventory used for the CRA-2019 PA.	*In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of container movement associated with salt creep and roof falls. DOE did not respond to this request. Since 2014 the maximum fissile mass loading of Criticality Control Overpacks (CCOs) and Pipe Overpacks (POPs) has been increased and container movement associated with these mechanisms has received increased attention in nuclear criticality evaluations as a mechanism for container clustering. The potential for clustering under WIPP conditions has been studied numerically by Reedlunn and Bean (2019) and the results of their analyses have been evaluated for nuclear criticality by Rechard (2019). The results of these studies are also relevant to this FEP. Please see the Agency's discussion of W28 Nuclear Explosions for additional information. The screening argument for W33 should be modified to address movement of containers from roof falls. This EPA concern addresses consistency within the FEP screening process and is unlikely to affect repository performance.* *Rechard, R.P. 2019. Improbability of TRU Waste Compaction by Salt Creep Causing Criticality in Bedded Salt Repository. November 2019. Albuquerque, NM: Sandia National Laboratories. ERMS 572199.* *Reedlunn, B., and J. Bean. 2019. Simulations of Pipe Overpack Container Compaction at the Waste Isolation Pilot Plant. October 2019. Albuquerque, NM: Sandia National Laboratories. SAND2019-12111.*	Screening argument needs to be updated with new information for CRA-2024
W40 Brine Inflow	Updated to reflect new parameter distribution for PBRINE, and elimination of panel closures in south end of repository.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with information on the impacts of changes in GLOBAL:PBRINE and the PCS on brine inflow. In response, DOE stated that this type of information is best left in the supporting documentation, rather than within the screening document, and provided references to the relevant supporting documentation. However, the impact of these model changes, of allowing more brine to flow into the waste panels, is identified in the SCR-2019 screening argument.*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
W42 Fluid Flow Due to Gas Production	Updated to reflect new parameter distribution for PBRINE and the removal of two sulfidation reactions refinement of the hydromagnesite conversion process.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with information on the impacts of changes in GLOBAL:PBRINE and the PCS on the availability of brine in the waste panels. In response, DOE stated that this type of information is best left in the supporting documentation, rather than within the screening document, and provided references to the relevant supporting documentation. However, the impact of these model changes, of allowing more brine to flow into the waste panels, is identified in the SCR-2019 screening argument.*	Accepted
W43 Convection	Updated to reflect the inventory used for the CRA-2019, underground experiments, and reference correction to mined volume in experimental area.	Screening argument accepted.	Accepted
W44 Degradation of Organic Material	Updated to reference new inventory used for CRA-2019 PA and EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with supporting documentation regarding the importance of the availability of brine to the degradation process. In response, DOE clarified that the experiments reported by Francis and Gillow (1994) investigated microbial gas generation under a wide range of repository conditions including humid and inundated conditions.* *Francis, A.J., and J.B. Gillow. 1994. Effects of Microbial Gas Processes on Generation Under Expected Waste Isolation Pilot Plant Repository Conditions, Progress Report through 1992. Albuquerque, NM: Sandia National Laboratories. SAND93-7036. ERMS 210673.*	Accepted
W45 Effects of Temperature on Microbial Gas Generation	Updated to reference new inventory used for CRA-2019 PA and EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of the reduced thermal impact of concrete hydration because of the elimination of additional explosion walls and the Option D monolith. In response, DOE stated that the calculated thermal rise in the screening argument was considered bounding due to the reduced concrete volume. DOE also noted that hydration of concrete in the remaining constructed elements of*	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		repository closure, such as shaft seals, will have largely abated by the time AICs are assumed to no longer prevent drilling into the repository, and therefore will have no substantial long-term effect on waste isolation. Additional discussion is provided in W73 Concrete Hydration.	
W48 Effects of Biofilms on Microbial Gas Generation	Updated to reflect the inventory used for the CRA-2019.	Screening argument accepted.	Accepted
W47 Effects of Radiation on Microbial Gas Generation	Updated to reflect the inventory used for the CRA-2019.	Screening argument accepted.	Accepted
W49 Gases from Metal Corrosion	Updated to reference new corrosion rates of steel and to reflect the inventory used for CRA-2019 PA.	*The comments on W5 also apply to W49.*	Should be revised for CRA-2024 with new information
W51 Chemical Effects of Corrosion	Updated to reference new corrosion rates of steel and to reflect the inventory used for CRA-2019 PA.	*The comments on W5 also apply to W51.*	Should be revised for CRA-2024 with new information
W52 Radiolysis of Brine	Updated with new analysis that demonstrates gas from radiolysis of brine no longer insignificant contributor to overall gas quantity.	Screening argument accepted.	Accepted
W53 Radiolysis of Cellulose	Updated to account for matrix depletion.	*In the CRA-2014 completeness review, EPA requested DOE to clarify the screening argument by explaining an inconsistency in Appendix SCR-2014 between Table SCR-1 and Section SCR-6.5.1.7.3, where the update is due to new radionuclide inventory, and Section SCR-6.5.1.7.2 where the update is due to new cellulose inventory. In response, DOE clarified that update was due to new waste inventory data that lowered the overall activity for all TRU radionuclides, supporting the previous conclusion that radiolysis of cellulose will not be a significant process in gas generation. Appendix SCR-2019 was further updated to show that gas generation from radiolysis of cellulose would be insignificant compared to other processes due to depletion of the finite waste matrix material source term. Upon review, EPA found that this conclusion was based on a study that assumed a greater than average radiological activity in the waste than is actually projected for the WIPP, resulting in a more rapid*	Inadequate, needs additional analysis for CRA-2024

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		*matrix depletion than would actually occur. In addition, the gas generation rates in DOE's study may have been underestimated. The Agency requested DOE to reevaluate the effect of radiolysis based on the actual predicted average waste activity and on a constant, bounding value for the gas generation rate. The results demonstrated that gas generation is dominated by anoxic corrosion of iron, that the CPR inventory is likely to be a limiting factor in some PA vectors, and that the results of the bounding gas generation calculations show that CPR radiolytic gas generation will have only small effects on repository releases. DOE has adequately demonstrated that the effects of gas generation from CPR radiolysis will be relatively unimportant based on currently available information. EPA expects the screening argument for W53 to be supplemented by a discussion of the results of these analysis for the CRA-2024. Additional discussion of these analyses is presented in EPA's Technical Support Document "*Evaluation of the Compliance Recertification Application (CRA-2019) Actinide Source Term, Gas Generation, Backfill Efficacy, Water Balance, and Culebra Dolomite Distribution Coefficient Values" *(Docket ID No. EPA-HQ-OAR-2019-0534)*	
W54 Helium Gas Production	Updated to reflect new inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W55 Radioactive Gases	Updated to reflect new inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W56 Speciation	Reference made to new solubility calculations based on new inventory components.	*The effect of cementitious materials in the shaft seals on repository pH and actinide solubility in W8 is also relevant to W56.*	Screening arguments do not adequately support screening decision and should be revised for CRA-2024
W67 Localized Reducing Zones	Updated to reflect gas generation from radiolysis.	Screening argument accepted.	Accepted
W68 Organic Complexation	Updated to reflect new solubility calculations for use in the CRA-2019 PA.	Screening argument accepted.	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
W69 Organic Ligands	Updated to reflect new solubility calculations for use in the CRA-2019 PA.	Screening argument accepted.	Accepted
W74 Chemical Degradation of Shaft Seals	Update to reflect additional shaft.	Screening argument accepted. *Contrary to the DOE reported change, the screening argument does not mention the additional shaft. However, EPA accepts the screening argument because the new shaft will be sealed in the same manner as the four existing shafts and the argument for the existing shafts therefore also applies to the additional shaft. A detailed review of DOE plans for a new fifth shaft is presented in EPA Technical Support Document* "Review of DOE Planned Change Notice for a Fifth Shaft at the WIPP Repository" *(Docket ID No. EPA-HQ-OAR-2019-0534).*	Accepted
W115 Chemical Degradation of Panel Closures	Updated screening argument per EPA comment.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to supplement the screening argument with a discussion of the chemical degradation of the steel bulkheads, which are part of the ROM salt panel closure system. DOE responded by providing the requested discussion.*	Accepted
W78 Colloid Transport	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	Screening argument accepted.	Accepted
W79 Colloid Formation and Stability	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	Screening argument accepted.	Accepted
W80 Colloid Filtration	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	Screening argument accepted.	Accepted
W81 Colloid Sorption	Updated to reflect the inventory used for the CRA-2019 and updated colloidal source term.	Screening argument accepted.	Accepted
W84 Cuttings	Updated to reflect new implementation in Panel 9.	Screening argument accepted.	Accepted
W85 Cavings	Updated with new waste shear strength data and implementation in Panel 9.	Screening argument accepted.	Accepted

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
W86 Spallings	Updated to reflect new implementation in Panel 9.	Screening argument accepted.	Accepted
W87 Microbial Transport	Updated with reference to new colloidal actinide source term and colloidal actinide parameters.	Screening argument accepted.	Accepted
W89 Transport of Radioactive Gases	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted
W93 Soret Effect	Updated to reflect the inventory used for the CRA-2019 PA.	Screening argument accepted.	Accepted

Note: Yellow highlighted blocks indicate concerns that are deserving of special attention and may potentially be more significant to repository performance.

Table 3. Changes Identified by EPA in CRA-2019 FEP Baseline

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
N3 Changes in Regional Stress N4 Regional Tectonics N5 Regional Uplift and Subsidence	No change.	*These three tectonic FEPs were the subject of EPA's Completeness Comment CC4-SCR-6a. The Agency noted that since the CCA was submitted in 1996 and first recertified in 2004, only a small number of Natural (N) FEPs appear to have received updates. Substantial new information on the geology of the Delaware Basin has emerged over the past decade, including several DOE-funded studies directly related to relevant natural FEPs which are neither mentioned nor referenced in Appendix SCR. EPA provided several examples in its Completeness Comment of recent studies related to tectonics and faulting that have potential relevance to the WIPP.* *In response, DOE acknowledged that not a great deal of time has been invested since the CCA in re-evaluating FEPs that relate to the natural system because the evidence indicates that the original screening decisions would not have been changed. Nevertheless, DOE agreed that such screening arguments may benefit from updated information in future CRAs.* *EPA appreciates DOE's recognition of the benefits of maintaining FEP screening arguments based on current data, even though such updates*	Adequate, but should be revised for CRA-2024

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		may be unlikely to affect repository performance. EPA expects that the screening arguments for FEPs related to the natural system will be updated for the CRA-2024 and particularly those related to tectonics and faulting. Further discussions of EPA's concerns and DOE's responses are presented under Completeness Comment CC3-SCR-6 in Appendix A.	
N18 Deep Dissolution N19 Solution Chimneys* N20 Breccia Pipes N21 Collapse Breccias H34 Borehole-Induced Solution and Subsidence H59 Solution Mining for Other Resources	No change.	*These six FEPs are related to natural and human-induced dissolution features and were the subject of EPA's Completeness Comment CC4-SCR-6b. This comment parallels that of CC4-SCR-6a in observing that Appendix SCR fails to discuss or even mention multiple recent studies of karst in the WIPP region, including what may be considered as the most comprehensive, authoritative, DOE-funded, SNL study, which was mandated and reviewed by EPA.* *In response, DOE acknowledged that karst remains a research topic of interest regionally as well as in the vicinity of WIPP but that it has not been considered a process of import within the LWA because no caves, cavernous porosity, or hydrologic indications of karst have been found within the WIPP site. As a result, DOE's conclusions for screening-out these FEPs remain unchanged.* *EPA accepts the DOE response. DOE adequately identified several karst-related processes and events in the region and justified their exclusion from consideration in WIPP PA. DOE has agreed to update its discussion of karst and cite more recent publications in the CRA-2024 even though such updates may be unlikely to affect repository performance. Further discussions of EPA's concerns and DOE's responses are presented under Completeness Comment CC3-SCR-6 in Appendix A.*	Adequate, but should be revised for CRA-2024
H26 Groundwater Extraction	No change.	*Recent pumping from a private well on the Mills Ranch and its effect on diverting groundwater flow directions in the Culebra within the LWA has been described by Thomas et. al. (2017) and should be addressed in the screening argument. Although the Agency does not expect this concern to have a significant effect on repository performance because releases from the Culebra are very low, the current shift toward increasing industrial use of recycled water and brine and its potential impact on the*	Adequate, but should be revised for CRA-2024. Deserves special attention (see Section 3.0)

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		Culebra as a release pathway should also be discussed either directly or by reference. *Thomas, M.A., K.L. Kuhlman, and A.L. Ward. 2017. Anthropogenic Influences on Groundwater in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico, USA. SAND 2016-9292c.* *EPA's Technical Support Document* "Review of Groundwater Flow and Radionuclide Transport Conceptualization in the Culebra Dolomite" *(Docket ID No. EPA-HQ-OAR-2019-0534) contains further detail on the Agency's questions and concerns regarding Culebra hydrogeology.*	
W27 Gas Explosions	No change.	Screening argument accepted. *In the CRA-2014 completeness review, EPA requested DOE to update the screening argument for this FEP with a discussion of the waste inventory that resulted in a 2014 accidental radiological release within the repository. DOE responded by stating that reviews of the accident concluded that there was no evidence of an explosion and that the requested discussion was best presented in FEP W72 Exothermic Reactions.*	Accepted
W50 Galvanic Coupling (within the Repository)	No change.	*Galvanic coupling can result in accelerated gas generation from accelerated corrosion of the anodic metal. Galvanic coupling within the repository has been screened out from WIPP PA based on the preponderance of iron over other metals in the repository. In Completeness Comment CC5-SCR-8, the Agency requested DOE to determine whether galvanic coupling between iron and lead in WIPP waste and packaging materials can continue to be screened out despite the increased lead inventory from shielded containers in the CRA-2019 PA. In response, DOE stated that there is insufficient information to determine the impact of galvanic coupling on WIPP PA but it is their opinion that galvanic coupling between lead and ferrous iron may have little influence on gas generation rates and should continue to be screened out.* *EPA concurs that there is currently no evidence that galvanic corrosion will be a significant process in the WIPP repository. However, the current screening argument for this FEP relies only on the preponderance of iron in the inventory. It does not address the much*	Adequate, but should be revised for CRA-2024

FEP	DOE Reported Change	EPA Comments	EPA Review of Screening Argument
		larger lead inventory introduced in CRA-2019 and it does not emphasize that galvanic coupling would not significantly affect gas generation. It is also unclear from site-specific lead corrosion experiments that lead surfaces will be passivated in the repository. Although the Agency does not expect this concern to have a significant effect on repository performance, EPA expects that the screening argument for this FEP will be updated for CRA-2024 to address the increased mass of lead. Additional details of EPA's completeness concern and DOE's response are documented in CC5-SCR-8 in Appendix A.	
W?? Brine Consumption by Radiolysis	New FEP	Addition of a New FEP *Although FEP W52 addresses radiolysis of brine, its focus is on gas generation rather than brine consumption. EPA is unaware of a FEP addressing brine consumption by radiolysis and requests DOE to include such a FEP in the updated 2024 FEP baseline. EPA understands that this process is included in water balance calculations in WIPP PA and the addition of this FEP to the baseline will provide the necessary supporting documentation.*	N/A

Notes:
- FEP N19 *Solution Chimneys* was combined with FEP N20 *Breccia Pipes* in the CRA-2004 and removed as a separate FEP from the FEP baseline.
- Yellow blocks indicate concerns deserving special attention that may potentially impact repository performance.

3.0 EPA Assessment of SNL'S CRA-2019 FEP Review

EPA accepts SNL's screening classifications and arguments for 71 of the 84 FEPs identified by SNL as changed for the CRA-2019 PA. For the 13 remaining FEPs, the Agency accepts the screening classifications but has residual concerns. The screening arguments for FEPs H5, H26, W5, W8, W33, W49, W51, W53, and W56 need to be expanded in scope or updated; the screening arguments for FEPs N71 and W23 need to be reevaluated; and the screening arguments for FEPs H31 and H32 need to be replaced. These latter two arguments both describe a revised methodology for calculating borehole plugging frequencies that was not accepted by EPA. The basis for this decision is summarized below and is described in detail in the Agency's TSD *Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment* (Docket ID No. EPA-HQ-OAR-2019-0534). As previously noted, the Agency's evaluations of all changed FEPs identified by SNL are summarized in Table 2. Additional background information is provided for some Agency comments to help explain their context. In addition, EPA identified five FEPs or groups of FEPs that the Agency considers to have changed since 2014 but that SNL reported as having 'no change.' The results of the Agency's review of these additional FEPs are summarized in Table 3.

Table 3 also includes a new waste-related FEP *Brine Consumption by Radiolysis* that EPA proposes to be added to the baseline. EPA is unaware of a FEP addressing this subject, though the Nuclear Energy Agency (NEA) identifies radiolysis of the fluid phase in a repository as a FEP for consideration (Capouet et al. 2019). EPA understands that this process is included in water balance calculations in WIPP PA and the addition of this FEP to the baseline will provide the necessary supporting documentation.

The Agency provided DOE with completeness questions for 32 FEPs, of which 22 were "natural" (or N) FEPs that had not received significant updates since the screening arguments were originally prepared for the 1996 CCA. These questions, DOE responses, and the Agency's evaluations of DOE's responses are presented in Appendix A. Of the 32 FEPs further addressed as completeness questions, satisfactory resolutions including modifications to screening arguments were provided by DOE for 17 FEPs but EPA had residual concerns for the screening arguments for the remaining 15 FEPs.

EPA's general concern regarding a lack of screening argument updates for many "natural" FEPs in SNL's CRA-2014 FEP baseline review was insufficiently resolved in SNL's CRA-2019 FEP baseline review. Many of the Agency's overall concerns about SNL's CRA-2019 FEP review process are associated with lack of current information. For example, the screening arguments for several key FEPs cite the 1996 CCA for further information. The screening arguments supporting the original FEP baseline for the CCA were well researched and comprehensive; however, an increasing disparity exists between the evolving repository design, PA modeling approaches, and the CCA screening arguments that should be corrected. Routine updating of screening arguments based on new scientific knowledge helps to demonstrate DOE's continuing awareness of relevant site conditions and should be pursued even if the additional information does not change the screening results as EPA anticipates for most FEPs.

Four FEPs that may require additional analysis were identified by EPA as deserving special attention by DOE when preparing the CRA-2024 PA are discussed below. However, none of the concerns identified by EPA are likely to have a significant impact on repository performance.

FEP N71 Microbes. The DOE conclusion that microbes are rapidly filtered out and do not migrate with advective flow in the Culebra is primarily based on column tests with crushed Culebra dolomite. The crushed dolomite bears little resemblance to the conceptual model of the Culebra where advective flow occurs primarily in a network of fractures and vugs. In a single test performed on actual Culebra core, the movement of microbes was reduced but not eliminated (Lucero et al. 1996). Insufficient information was presented to support DOE's conclusion that the movement that did occur was of no consequence to WIPP PA or that the core sample itself was representative of the lower transmissive zone of the Culebra. EPA expects DOE to review the screening argument for this FEP for the CRA-2024 and either screen it in into WIPP PA or provide an adequate justification for continuing to screen it out.

FEP H26 Groundwater Extraction. Recent pumping from a private well on the Mills Ranch (Thomas et al. 2017) and its effect on diverting groundwater flow directions and velocities in the Culebra within the LWA should be addressed, along with any other significant new hydrogeological investigations in the screening argument for this FEP. The current shift toward increasing industrial use of recycled water and brine and its potential impact on the Culebra as a release pathway should also be addressed either directly or by reference.

FEP H31 Natural Borehole Fluid Flow. The screening argument for this FEP describes a new method for calculating borehole plugging frequencies that has not been accepted by EPA because it was not adequately supported by regulatory considerations or by current practice. A detailed review of the new method and the Agency's concerns and conclusions are presented in the Agency's Technical Support Document *Review of Borehole Drilling Rate and Plugging Pattern Frequency Calculations in the CRA-2019 Performance Assessment* (Docket ID No. EPA-HQ-OAR-2019-0534). EPA expects DOE to revert to the previously-approved methodology for calculating plugging pattern probabilities in the CRA-2024 PA, or otherwise propose alternative methods that may be approved by EPA prior to that time.

FEP W23 Subsidence. The effects of subsidence on the Culebra due to mining are treated in the WIPP PA, per regulatory requirement, as multipliers of the base-case Culebra transmissivities. This is appropriate because those transmissivities are based on geohydrologic field data that do not incorporate subsidence due to mining because the mining has not yet occurred. Although complete subsidence due to repository excavations has also not yet occurred, DOE argues that the effect on the Culebra is intrinsically incorporated in the base-case field data. EPA is unaware of any documentation describing how Culebra transmissivity fields have been modified to account for subsidence due to repository excavations. The effects of future mining and related subsidence are uncertain to occur while the effects of subsidence due to repository excavations are certain to occur. EPA expects that, for CRA-2024, the screening argument for this FEP will be updated to either screen in an increase Culebra transmissivity in the WIPP PA by a technically justified amount due to repository excavations, or to provide a demonstration that such an increase can continue to be screened out.

4.0 EPA Conclusions

The Agency concludes that SNL's FEP review successfully identified most FEPs that have changed since the 2014 baseline was completed and addresses the principal modeling changes that were necessary to achieve the purpose of the CRA-2019 PA. Table 4 provides a summary of EPA expectations for improving CRA-2019 FEP screening arguments. EPA accepts SNL's updated FEP baseline as sufficient for the CRA-2019 PA and expects that none of the concerns identified by EPA are likely to have a significant impact on repository performance. However, EPA expects DOE to address and resolve the concerns raised by the Agency in the FEP baseline review for the CRA-2024. The Agency's expectation applies to all FEPs identified in this TSD as having residual concerns with special attention given to the four FEPs identified above.

Table 4. Summary of EPA Expectations for Improving CRA-2019 FEP Screening Arguments

FEP	EPA Expectations
N3 Changes in Regional Stress N4 Regional Tectonics N5 Regional Uplift and Subsidence	EPA expects that the screening arguments for FEPs related to the natural system, and particularly those related to tectonics and faulting, will be updated for the CRA-2024.
N18 Deep Dissolution N19 Solution Chimneys* N20 Breccia Pipes N21 Collapse Breccias H34 Borehole-Induced Solution and Subsidence H59 Solution Mining for Other Resources	EPA expects that DOE will update its discussion of karst and cite more recent publications in the CRA-2024.
N71 Microbes	EPA expects DOE to review the screening argument for FEP N71 for the CRA-2024 and either screen it in into WIPP PA or provide an adequate justification for continuing to screen it out.
H5 Groundwater Exploitation H26 Groundwater Extraction	FEP H5 addresses groundwater exploitation and FEP H26 addresses groundwater extraction. EPA expects the difference between "exploitation" and "extraction" to be explained and the combined screening argument for FEPs H3 and H5 to be expanded to address groundwater exploitation consistent with the provided definition.
H26 Groundwater Extraction	EPA expects that the potential impact on groundwater flow direction and velocity in the Culebra release pathway due to increasing industrial use of brackish and recycled water, as illustrated by recent pumping from a private well on the Mills Ranch, will be discussed either directly or by reference in the screening argument for FEP H26 in the CRA-2024 baseline.
H31 Natural Borehole Fluid Flow H32 Waste-Induced Borehole Flow	The screening argument for these FEPs includes a new method for calculating borehole plugging frequencies that has not been accepted by EPA. EPA expects DOE to revert to the previously-approved methodology for calculating plugging pattern probabilities in the CRA-2024 PA, or otherwise propose alternative methods that may be approved by EPA prior to that time, and to modify the screening argument for these FEPs accordingly.
W5 Container Material Inventory W49 Gases from Metal Corrosion W51 Chemical Effects of Corrosion	EPA expects the results of additional calculations on gas generation from lead corrosion requested by EPA and conducted by DOE to be included in the screening argument for these FEPs in the CRA-2024.
W8 Shaft Seal Chemical Composition W56 Speciation	EPA expects the DOE to revise the screening arguments for these FEPs consistent with the Department's response to the Agency's Completeness Comment CC5-SCR-7.
W23 Subsidence	EPA expects that, for the CRA-2024, the screening argument for FEP W23 will be updated to either screen in an increased Culebra transmissivity in WIPP PA by a technically justified amount within the area affected by subsidence due to WIPP excavations, or to provide a demonstration that such an increase would have a negligible impact on the Culebra release pathway and can continue to be screened out.
W33 Movement of Containers	EPA expects that the screening argument for FEP W33 will be modified to address movement of containers from roof falls.

W50 Galvanic Coupling (within the Repository)	EPA expects that the screening argument for FEP W50 will be updated for CRA-2024 to address the increased mass of lead in the WIPP inventory.
W53 Radiolysis of Cellulose	EPA expects the screening argument for FEP W53 to be supplemented by a discussion of the results of DOE's reevaluation of the effect of radiolysis for the CRA-2024.

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Zeitler, T.R. 2018. *Bounding Calculation of the Cumulative Distribution for STEEL:HUMCORR.* Carlsbad, NM: Sandia National Laboratories. ERMS 569807.

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APPENDIX A

EPA Completeness Questions, DOE Responses, and EPA Evaluations of Responses Related to Features, Events and Processes in WIPP Performance Assessment

Table A-1. Summary of EPA Completeness Questions and DOE Responses in this TSD

Question	Topic	DOE Response Set	Evaluation/Resolution	Documentation/ Discussion in TSD
CC3-SCR-1	Supplemental Information for FEP N71 Microbes	#6 (10/26/20)	Partially adequate; information on microbial size provided, but discussion inadequate on filtration	Exec Summary, Sections 2.2, 3.0, 4.0, Appendix A
CC3-SCR-2	Supplemental Information for FEP W22 Roof Falls	#6 (10/26/20)	Satisfactory, screening argument expanded	Sections 2.2, 4.0, Appendix A
CC3-SCR-3	Updates for FEP W23 Subsidence	#6 (10/26/20)	Partially adequate, updated discussion deferred to CRA-2024	Exec Summary, Sections 2.2, 3.0, 4.0, Appendix A
CC3-SCR-4	Supplemental Information for FEP W28 Nuclear Explosions	#6 (10/26/20)	Satisfactory; screening argument will be updated in CRA-2024	Section 2.2, Appendix A
CC3-SCR-5 a-b	Supplemental Information for FEP N12 Seismic Activity	#6 (10/26/20)	Satisfactory; discussion should be expanded for CRA-2024	Section 2.2, Appendix A
CC4-SCR-6 a-b	N FEPs updates	#7 (12/1/20)	Satisfactory; additional information and discussion will be provided in CRA-2024	Sections 2.2, 3.0, 4.0, Appendix A
CC5-SCR-7	Effects of Cementitious Components of Repository Shaft Seals (FEPs W8 and W56)	#9 (3/4/21)	Partially adequate response; screening arguments should be revised	Sections 2.2, 4.0, Appendix A
CC5-SCR-8	Screening Argument for Galvanic Coupling Within the Repository (FEP W50)	#10 (3/30/21)	Satisfactory; discussion should be updated and expanded for CRA-2024	Sections 2.2, 4.0, Appendix A
CC5-SCR-9	Screening Decision for Gas Generation by Lead Corrosion (FEPs W5 and W49)	#10 (3/30/21)	Satisfactory; calculations provided	Sections 2.2, 4.0, Appendix A
CC5-SCR-10 a-c	N FEPs and Related Updates	#10 (3/30/21)	Partially adequate; DOE did not directly acknowledge or answer all questions; screening arguments should be reviewed and updated for CRA-2024	Sections 2.2, 3.0, 4.0, Appendix A
CC6-SCR-11	Updates to Seismic Activity FEPs	#10 (3/30/21)	Partially adequate; additional, updated information and discussion should be provided in CRA-2024	Section 2.2, Appendix A

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CC3-SCR-1 Supplemental Information for FEP N71 Microbes
40 CFR § 194.23 Models and Computer Codes

Please supplement the argument for screening out microbial colloidal transport in the Culebra (FEP N71) to 1) account for the ranges of sizes of indigenous microbes found in Culebra groundwater that are capable of transporting actinides as colloids, and 2) provide information supporting the assertion that those microbes would be rapidly filtered out.

> *Colloidal transport in the Culebra by naturally occurring microbes is screened out of WIPP PA on the basis that they would be rapidly filtered out because of their size. The screening argument statement (page SCR-68) "The dimension of the cells are 0.75 micrometer (μm) in length and 0.58 μm in width…" is misleading because it implies that all microbes in the Culebra are the same size and does not account for variations that occur in nature. Also, no supporting information is provided, either directly or by reference, that substantial filtering would actually occur. Screening out transport by indigenous microbes based on low consequence is not adequately supported.*

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

Microbial colloidal contributions to the source term in the Culebra are screened out of performance assessments (PA) based on the assumption that affected microbes will not be transported through the Culebra dolomite member. This assumption depends not only on the traits of the microbes but also on the porosity and transmissivity of the Culebra. If dissolved actinides are introduced into the Culebra, their solution concentration could be reduced due to sorption onto indigenous mineral fragments, microbes, and humic substances. The physical and chemical behavior of these newly formed actinide-bearing colloidal particles resembles the behavior of colloids introduced from the repository to the Culebra. Microbes (and mineral fragments) will be rapidly filtered out of the advective flow domain; hence, disregarding the interaction between dissolved actinides and these types of colloids is considered to be a conservative approach. The following paragraphs support the assumption that microbes will not be transported through the Culebra.

It is well known that both microbial size and shape influence their filtration in porous media. Previous work has determined that if the "limiting dimension" of a cell is more than 5% of the mean diameter of grain particles in the porous matrix, then filtration-based retardation can be significant (Herzig, 1970; Pepper et al., 2014). Cell diameters typically range from 0.2-2.0 micrometers (μm) (Madigan et al., 2018), with the lowest recorded diameter of 0.12 μm in a marine bacterium (Rappé et al., 2002). The smallest documented archaea are nanohaloarchaea measured at 0.3-0.5 μm (Huber et al., 2002). Cell lengths are more variable and can reach up to hundreds of microns in length. Cell shape also influences retardation, and smaller, rounder morphologies tend to move more quickly through porous media. The size ranges observed for Culebra microorganisms were a width of 0.48 to ~1 μm and a length of 0.54 to 3.5 μm (see detailed list provided in Table 1).

Table 1. Summary of Cell Sizes of Microorganisms in WIPP Groundwaters

Source (as described in reference)	Length (µm)	Width (µm)	Reference
Culebra groundwater	0.82 ± 0.14	0.66 ± 0.14	Francis et al., 1998
WIPP-1A culture (*Halomonas* sp.)	1.53 ± 0.09	0.79 ± 0.03	Francis et al., 1998
Mixed culture* ("Brine A Bacteria", or BAB):	1.46 ± 0.45 (mean)	0.66 ± 0.07	Francis et al., 1998
Group A	0.54 ± 0.03	0.48 ± 0.03	
Group B	0.66 ± 0.01	0.62 ± 0.02	
Group C	1.47 ± 0.14	0.76 ± 0.04	
Group D	2.66 ± 0.29	0.92 ± 0.06	
Group E	7.73 ± 0.96	0.67 ± 0.04	
Culebra groundwater	0.75 ± 0.04	0.58 ± 0.02	Gillow et al., 2000
WIPP monitoring well (*Chromohalobacter* sp.)	3.5	0.5	Ams et al., 2013
WIPP monitoring well (*Halococcus* sp.)	~1	~1	Swanson et al., 2013
WIPP-1A culture (*Halomonas* sp.) formalin-fixed	No measurements of length and width; measurements of cell volumes range from 0.2-0.4 µm3		Lucero et al., 1996

*Based on descriptions of pink pigmentation, this culture is presumed to be and/or contain haloarchaea; many of these organisms are pleomorphic, so it is likely that some of these groups are different morphologies of the same organism. The culture was enriched from a mixture of muck pile salt, area brine lake sediment and slurry, and G-seep brine.

When actively growing (i.e., in the presence of nutrients), most cells will increase in size. Some microorganisms also change morphology depending upon their growth phase (e.g., select Actinobacteria). Other factors affecting cell size and shape include the use of fixatives to preserve cells for experiments (e.g., formalin; del Giorgio et al., 1996), the presence of high ionic strength which can lead to dormancy and miniaturization (Fendrihan et al., 2012), and the

presence of ethylenediaminetetraacetic acid (EDTA), which is sometimes used to remove the outer layer of cells and promote "rounding" (Dyall-Smith, 2009). Conditions in the Culebra will cover a range of ionic strengths and will likely be nutrient poor.

Studies have also been conducted on microbial transport through crushed and intact Culebra rock (see Table 2; Yelton et al., 1996; Lucero et al., 1996; Zengotita et al., 2019). It should be noted that the maximum column length in these studies was ~44 cm (Yelton et al., 1996), while the distance-to-release pathway from the center of WIPP to the land withdrawal boundary is roughly 2.7 km (Kuhlman, 2010).

Yelton et al. (1996) found that the flow of latex microspheres (ranging in diameter from 0.48 – 1.05 μm to approximate microbial sizes) through crushed dolomite was significantly retarded under their test conditions, even when larger grains were used (maximum elution of 11% of the smallest spheres at the larger grain size). Microbial cells in the presence of nutrients caused complete blockage of the crushed dolomite. In the absence of nutrients, less than 1% of the injected cells broke through. More retardation occurred when the dolomite particle size fraction was smaller or when the cell size was larger, as expected.

In similar experiments using an intact dolomite core with much lower porosity, Lucero et al. (1996) showed a reduction in the number of injected cells versus cells in the effluent, and it was suggested that the effluent cells may have already been resident within the core at the start of the experiment. The presence of bacteria did not affect the transport of uranium, americium, or plutonium through the column.

Zengotita et al. (2019) found that actively growing cells of Chromohalobacter sp. were retarded in crushed dolomite more than stationary phase cells (~65% recovery versus 80% recovery). These are similar to the results of Yelton et al. (above) and could have been due to either the straining of larger growing cells or differing surface characteristics that allowed for interaction with the dolomite. This study used a flow rate approximating the maximum hydraulic conductivity previously measured in the Culebra (10-5 m/s).

Early experiments (Papenguth and Behl 1996) and studies on the filtration of colloids have been the basis of the conceptual model for the transport of colloidal actinides in the Culebra since the Compliance Certification Application (CCA) (DOE 1996). CCA Appendix MASS, Section MASS.15.3 and associated attachments (MASS Attachment 15-8 and 15-9) (Stockman [1996] and Perkins [1996]) describe the experiments that support filtration of colloids within the Culebra and suggested treatment within PA. There have also been a number of studies since the time of the CCA (See Tables 1 and 2) that support these earlier results. Based on all of these studies, microbes and mineral fragments are conceptualized as being larger than the mean pore-throat diameter in Culebra diffusive porosity. Therefore, colloid transport of actinides is screened out based on size of the microbes and the Culebra media pore size as supported by the experiments discussed above.

Table 2. Summary of Conditions in Microbe-Culebra experiments

Cells	Eluent	Flow Rate	Grain size fraction	Average porosity	Reference
Mixed culture (from Francis & Gillow, 1994); binned into different size fractions, ranging 0.2-1 µm length; stationary phase live	3 m brine simulant, primarily NaCl	0.5 mL/min	250-500 nm	0.46	Yelton et al., 1996
Mixed culture (from Francis & Gillow, 1994); binned into different size fractions, ranging 0.2-1 µm length; preserved at stationary phase using formalin				0.44	
WIPP-1A culture (*Halomonas* sp.) + possible indigenous organisms from crushed dolomite (cells formalin-fixed prior to size determination but not fixed for experiment)	Brine simulant, low sodium (~0.6 M)	0.1 mL/min	Intact core	0.15	Lucero et al., 1996
Chromohalobacter sp.; stationary phase live	2.6 M NaCl + 15 mM bicarb	0.013 mL/min	355-500 µm	0.43	Zengotita et al., 2019
Chromohalobacter sp.; dimensions; stationary phase "heat-stressed"					
Chromohalobacter sp.; dimensions; log phase					

DOE References

References with hyperlinks were provided in prior CRAs. The remainder of the reference documents will be provided in Enclosure 4 or as otherwise noted.

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Huber, H., M. Hohn, R. Rachel, T. Fuchs, V. Wimmer and K. Stetter. 2002. A new phylum of archaea represented by nanosized hyperthermophilic endosymbiont. Nature 417: 63-67.

Kuhlman K. 2010. Analysis Report for the CRA-2009 PABC Culebra Flow and Transport Calculations. Sandia National Laboratories; Carlsbad, NM. AP-144. ERMS 552951

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Peper, I., C. Gerba and T. Gentry (eds). 2014. Environmental Microbiology. 3rd Edition. Academic Press; London. This reference was provided with CRA-2019.

Rappé, M., S. Connon, K. Vergin and S. Giovannoni. 2002. Cultivation of the ubiquitous SAR11 marine bacterioplankton clade. Nature 418: 630-632.

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*Yelton, W., Y. Behl, J. Kelly, M. Dunn, J. Gillow, A. Francis and H. Papenguth. 1996. Laboratory Evaluation of Colloidal Actinide Transport at the Waste Isolation Pilot Plant (WIPP): 1. Crushed- Dolomite Column Flow Experiments. Sandia National Laboratories; Albuquerque, NM. SAND96- 2894C

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EPA Evaluation of Response

EPA's Completeness Comment has two parts. The first requests information on the ranges of sizes of microbes found in Culebra (or similar) groundwater and the second requests information supporting the assertion that the microbes would be rapidly filtered out because of their size and would not travel far. The first of these questions was satisfactorily answered by the abundance of size data presented in the DOE response. However, the second question was not satisfactorily answered.

Most of the information provided by DOE in response to the second question was developed from column tests of flow through crushed Culebra dolomite. Such tests may provide information on possible sorption but the crushing process would recast the dual porosity, fracture/matrix conceptual model of the Culebra as a single porosity porous medium. Two of the three cited references in Table 2 of the DOE response (Yelton et al. 1996 and Zengotita et al 2019) describe column tests on crushed dolomite. No explanation was found in the DOE response or in these two references of how physical filtration in a single porosity column of crushed dolomite can serve as an adequate surrogate for physical filtration in the actual dual porosity Culebra medium of fractures and matrix.

DOE's response states that "Based on all of these studies, microbes and mineral fragments are conceptualized as being larger than the mean pore-throat diameter in Culebra diffusive porosity." This suggests that most microbes cannot enter the matrix and must therefore remain within the advective flow domain of the fractures. This conceptual model further emphasizes the need to adequately consider fracture flow when evaluating microbial transport in the Culebra.

The third cited reference in Table 2 (Lucero et al 1996) describes filtration experiments in an intact Culebra core. This reference describes a column test on a Culebra core and came closest to providing the necessary fracture flow data. However, the information presented in the cited reference was insufficient to support the conclusion of rapid filtration. The format of the document suggests it was prepared as a symposium presentation of compressed length and descriptions of core selection and handling are missing. A discussion of these topics would help to validate the representativeness of the core for determining flow characteristics in the Culebra.

Field testing in the Culebra, for example, indicated that most of the flow occurs in the more highly fractured lower 4 m of the unit, which is where a representative core sample would have been taken (Meigs and McCord 1996, p. 5).

The use of live microbes in the test and the use of a non-sterile core also imposed difficulties in interpreting the results. The results of Lucero et al's column test are reproduced below in Figure A-1. The immediate presence of microbes in the effluent fluid at test startup suggests that either the microbes in the inoculant moved very quickly through the core or that the observed microbes were already in the core and were being flushed out by the injected brine. It was apparently difficult for the researchers to distinguish the inoculated microbes from native microbes.

The use of live microbes also introduced uncertainties related to population variations during the test. A surrogate "mock" brine was used for inoculant sampling purposes to avoid disturbing the actual inoculant during the test. An apparently unexpected temporary surge in microbial density in the mock inoculant from 2×10^6 to over 7×10^6 cells/ml was not observed in the effluent brine, which remained at a level of about 0.5×10^6 cells/ml throughout the test. This suggests that the surge in the surrogate inoculant may not have occurred in the actual inoculant. At the same time as the mock inoculant cell density surge occurred, the mock inoculant cell volume (measured in cubic microns) decreased and the effluent cell volume increased. This may be indicative of a flushing of larger resident cells from the core.

By the end of the test four liters of effluent had been collected, representing about 16 pore volumes of the 14.5 φ×10 cm core, and significant excursions in microbial density and volume had ceased. At the end of the test the mock inoculant cell density was greater than the effluent density and the mock inoculant cell volume was greater than the effluent volume. The decreases in effluent density and volume were attributed by the authors in part due to filtration (Lucero et al. 1996, p. 7) and in part due to the many eukaryotic organisms in the effluent that appeared to be generated in the test column itself and "…may have eaten a small portion of the injected bacteria." (Lucero et al. 1996, p. 5).

The DOE response concludes with citations of early experiments (Papenguth and Behl 1996) and documentation supporting the screening decision that microbial (and mineral fragment) colloids would be rapidly screened out in the Culebra (Stockman 1996; Perkins 1996). However, Papenguth and Behl (1996) is a test plan, not a test report. It describes the theoretical and conceptual basis for colloid retardation during transport and the tests to be conducted, but does not present results for the Culebra. Stockman (1996) provides a summary of a meeting to discuss treatment of Culebra transport in WIPP PA. She provides some results and opinions but does not describe or provide references to the supporting experiments, as that was not the purpose of her memo. Perkins (1996) provides a method of calculating filtration rates for mineral and microbial colloids. He applies his method to data obtained from Hans Papenguth from the results of column tests with crushed Culebra dolomite. No descriptions of or references to Papenguth's supporting experiments are given. No discussion is provided on the relevance of such tests to advective flow in Culebra fractures.

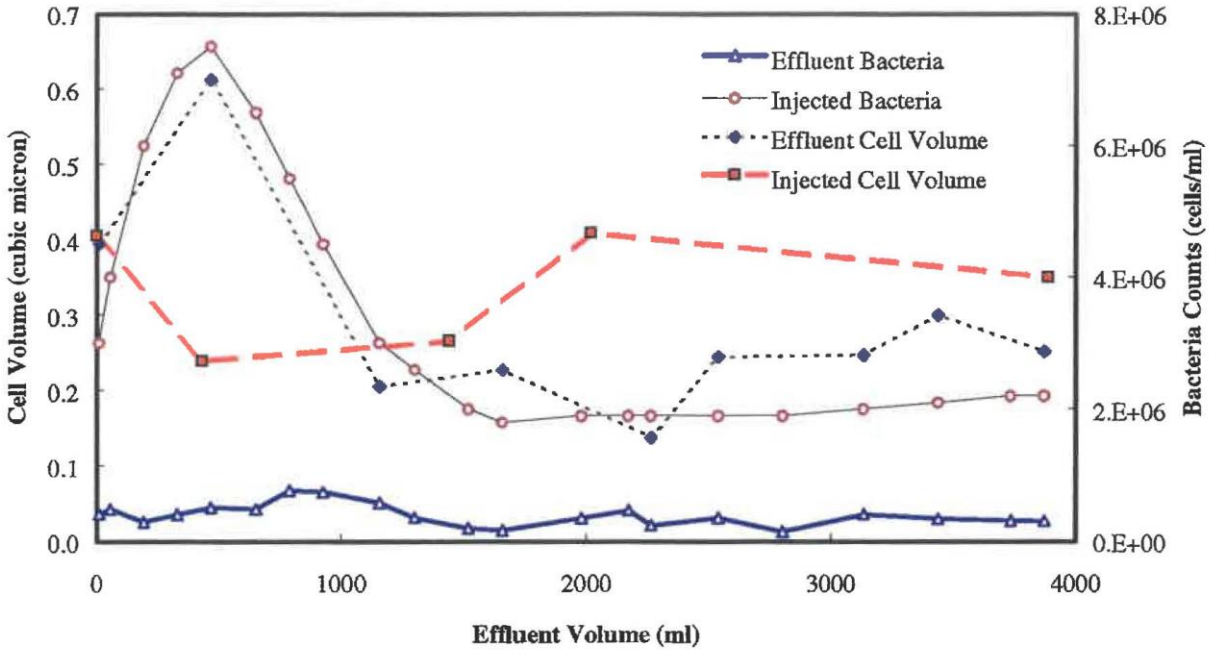


Figure A-1. Live microbe cell numbers and volume in effluent and mock injection brine (from Lucero et al. 1996, Figure 3).

EPA concludes that, although some microbes are likely filtered out during transport in the Culebra, the continued, persistent presence of a fraction of the injected microbes in the effluent brine of Lucero et al's (1996) test does not support the DOE's conclusion that all microbes are rapidly filtered out in the Culebra. This lack of support, coupled with the lack of documentation regarding the representativeness of the core sample used in the test and the inability of tests on crushed Culebra dolomite to adequately simulate flow through fractures, renders the DOE's conclusion of rapid microbe filtration to be inadequately supported. EPA's comments on FEP W23 Subsidence are also relevant to this FEP because vertical and horizontal strains associated with subsidence due to repository excavations as well as potential subsidence due to mining are expected to open existing fractures, increase Culebra transmissivity, and may decrease filtration. Please see Comment CC3-SCR-3 in this appendix. EPA expects DOE to review the screening argument for this FEP for the CRA-2024 and either screen it in into WIPP PA or provide an adequate justification for continuing to screen it out.

EPA References

Lucero D., Y. Behl, G. Brown, K. Budge, M. Dunn, A. Francis, J. Gillow and H. Papenguth. 1996. Laboratory Evaluation of Colloid Transport under Simulated Subsurface Conditions at the Waste Isolation Pilot Plant (WIPP): 2. Large-Scale-Intact-Core Column Flow Experiments. WPO 42864. Sandia National Laboratories; Albuquerque, NM. Also published as SAND96-2741J.

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CC3-SCR-2 Supplemental Information for FEP W22 Roof Falls
40 CFR § 194.23 Models and Computer Codes

Please supplement the screening argument for FEP W22 *Roof Falls* with a discussion of the effects of roof falls on the modeling of open rooms in WIPP PA.

> *The screening argument limits the impact of roof falls to the DRZ and does not address the impact of roof falls into open rooms that are not filled with waste. Repository design changes since the CCA now anticipate that large portions of the Waste Area will be closed off as open rooms subject to roof fall. EPA agrees with the screening statement that (page SCR-151) "In the long term, the effects of roof falls in the repository are likely to be minor because salt creep will reduce the void space and the potential for roof falls as well as promote healing of any roof material that has fallen into the rooms." However, uncertainties similar to those identified in the screening argument for the impacts of roof falls on the DRZ also apply to open rooms. The screening argument should be expanded to include the effect of roof falls on open rooms as well as the DRZ and their treatment in WIPP PA.*

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

Many of the uncertainties regarding the healing of the disturbed rock zone (DRZ) are similar to those uncertainties regarding the healing of rubble piles on the floors of empty rooms. However, the U.S. Department of Energy (DOE) continues to believe that the current treatment of the DRZ within the performance assessment (PA) addresses the uncertainty related to DRZ permeability during room closure and healing (see Appendix PA-2019, Section PA- 1.1.15). The following addition to FEP W22 will be made in Appendix SCR in the next update to address the empty

room case and will also be listed in the 2019 Compliance Recertification Application (CRA-2019) errata:

> "Cracks form in the DRZ, near the room, due to the lack of stiff support (confining pressure). These cracks can lead to blocks of salt detaching from the surrounding rock formation. If the room is filled with waste or crushed salt, the room contents will likely support these salt blocks such that they will partially mate up with the surrounding rock formation as the room closes. If surfaces mate up well, healing of fissures may happen relatively rapidly. When blocks detach around empty rooms, however, the blocks can fall several meters, land on the floor, and possibly break into smaller pieces. This rubble pile will almost certainly not mate up with the surrounding rock formation, meaning the surrounding rock must apply sufficient pressure to rearrange, break up, and heal the rubble pile. In both cases, the DRZ and empty rooms will eventually approach the porosity and permeability of intact salt, but the length of time required is not precisely known. In light of this uncertainty, the PA flow model uses wide ranges for DRZ permeability and DRZ porosity and bounding values for the permeability and porosity of empty rooms than are expected to remain in the long term."

EPA Evaluation of Response

The DOE response was satisfactory. The requested expansion of the screening argument to include the effect of roof falls on the creep closure of open rooms was provided.

CC3-SCR-3 Updates for FEP W23 Subsidence
40 CFR § 194.32 Scope of Performance Assessments

Please update the screening argument for FEP W23 *Subsidence* 1) to be consistent with the current repository design; and 2) to explain and justify the difference in treatment in WIPP PA between subsidence due to repository excavations and subsidence due to potash mining.

> *The calculated amount of subsidence due to repository excavations in the screening argument is based on the 1994 repository design and does not take into account the increase in volume and lateral extent of open rooms in the current design. The Agency estimates that the projected volume of open rooms at the time of closure has more than doubled (from ~130,000 to ~300,000 m3) since 1994, very likely resulting in increased subsidence. The screening argument has not been updated based on the current repository design*
>
> *The screening argument states that, based on the 1994 design, the potential one order of magnitude increase in Culebra horizontal hydraulic conductivity due to subsidence from repository excavations can be ignored because it is small compared with the range of uncertainty in Culebra conductivities. Subsidence due to repository excavations is potentially important to performance because, in WIPP PA, repository excavations are certain to occur while the occurrence of future potash mining is uncertain. Subsidence due to potash mining is treated in WIPP PA by increasing Culebra transmissivities by a sampled factor ranging from 1 to 1,000. Both sources of subsidence are assumed by DOE*

to result in spatially uniform increases in transmissivity. The increase due to the repository is in addition to the increase due to mining and lies within the range of increases considered for mining. Given that the increase due to the repository is not negligible, it is unclear why the two sources of subsidence are treated differently. The treatment of subsidence due to mining is appropriate because it retains the spatial correlation to field data inherent in the calculated Culebra T-fields. The treatment of subsidence from repository excavations is potentially as important but is not consistent with the treatment of subsidence from potash mining.

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

For the 2019 Compliance Recertification Application (CRA-2019), this FEP was updated to note the plans for an additional shaft and associated access drifts. It was not updated to reflect the absence of waste in Panel 9. This was an oversight and will be corrected in the next update of Appendix SCR for the CRA-2024. With regard to any additional subsidence associated with the absence of waste within this panel, the Backfill Engineering Analysis Report (Westinghouse 1994) analyzed the expected subsidence for mined areas in a variety of degrees of fill, including a completely empty area. Table 3-14 of Westinghouse (1994) shows a summary of these subsidence predictions. Depending on the predictive technique used, subsidence estimates for completely empty waste emplacement areas range from 0.55 to 0.95 meters. This is compared to a range of 0.33 to 0.55 meters for waste areas with waste and loosely emplaced backfill. As expected, the completely empty areas will have greater subsidence, but these small variations are expected to be within the current treatment of Culebra transmissivity.

Subsidence over the WIPP is well understood and monitored regularly. Subsidence data is reported annually in the Compliance Parameter Monitoring Assessment Report. Subsidence over the repository is trending as expected and includes repository areas that are completely filled, partially filled, and those with no waste or fill. Many of these mine workings have been mined for 30-35 years. Therefore, it is believed that current Culebra hydrology data intrinsically contain effects caused by subsidence over these areas and that the small changes caused by empty areas will continue to be within expected ranges.

As stated in the current screening argument, subsidence over Potash mines will be much greater than over WIPP (even with empty panels) because, 1) potash horizons are shallower than the WIPP horizon, and 2) potash mines have much greater extraction ratios (22% for WIPP disposal areas versus 65% for potash mines). Therefore, subsidence over potash mines can be up to 1.5 meters (Westinghouse 1994, p. 2-22). It follows, then that changes in transmissivity due to the effects of subsidence over potash mines would be greater than that over WIPP, which will have much lower degree of subsidence. This is consistent with the increase in transmissivity assumed in the mining scenario.

With regard to the apparent inconsistency between the treatment of the expected subsidence and its effects on Culebra transmissivity versus the treatment of transmissivity due to the mining scenario, the implementation of the mining scenario is very prescriptive as per EPA's Compliance Application Guidance (CAG) to 40 CFR §194.32. Per the CAG, the probability that

mining will occur is 1 in 100 per century, and Culebra transmissivity is varied randomly from 1 to 1,000. The basis of this range of permeability is not documented in the CAG.

The Culebra transmissivities used in mining are conditional; they are not considered "base-case" transmissivities. The current base-case transmissivities used in the non-mining scenarios are representative of years of data collection and studies of Culebra hydrology and are modeled as a steady-state process. The current transmissivities consider human activities including water production, oil production, and mining of the WIPP underground facility, and are believed to be adequate to account for the small degree of change in predicted subsidence for those areas of the repository that may not contain waste.

DOE Reference

Westinghouse Electric Corporation. 1994. Backfill Engineering Analysis Report, Waste Isolation Pilot Plant. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. ERMS 237909.

EPA Evaluation of Response

EPA's Completeness Comment has two parts. The first requests DOE to update the screening argument to be consistent with the current repository design that includes a large increase in the volume of open areas, and the second requests an explanation and justification of the difference in treatment in WIPP PA between subsidence due to repository excavations and subsidence due to potash mining.

In response to the first of these requests, DOE referred to a study documented in Westinghouse Electric Corporation (1994) that found the range of maximum predicted surface subsidence resulting from a completely empty repository waste emplacement area to be approximately double that resulting from a waste emplacement area containing waste and loosely emplaced backfill. DOE concluded that this difference was small and its effects on the Culebra were expected to be within the current treatment of Culebra transmissivity. EPA does not agree that the effect on the Culebra of a doubling of maximum predicted subsidence would necessarily be small because of the cubic relationship between fracture aperture and flow. However, EPA does agree that the effect may be small because the increases in open area are scattered across the repository footprint and much of the increase occurs in areas where the extraction ratio is lower than in the waste area, resulting in reduced subsidence. DOE needs to provide more information in the CRA-2024 FEP baseline review in order for EPA to determine whether the maximum predicted subsidence is "small".

Also in response to the first of these requests, DOE agreed that the screening argument was not updated to reflect the absence of waste in Panel 9 and that this was an oversight that will be corrected in the CRA-2024 submittal. While this response is acceptable, the Agency notes that repository design changes made since 1994 are not limited to the absence of waste in Panel 9 but also include the replacement for Panel 9, the access drifts to that replacement panel, the access drifts to a fifth shaft, and the expanded SDI/SDDI experimental areas. EPA expects the updates

to this screening argument to address the presence of these design changes as well as any other changes potentially affecting subsidence that are relevant to the CRA-2024 repository design.

The second request was also not satisfactorily answered. EPA agrees that the treatment of subsidence due to mining is prescribed in the rule and that the occurrence of mining is appropriately considered to be uncertain. EPA also agrees that subsidence due to mining, if it occurred, would be expected to have a greater effect than subsidence due to the WIPP excavations. The two sources of subsidence are similar in that neither has yet fully occurred. There has been no mining within the WIPP Land Withdrawal Area (LWA) and the full effects on Culebra hydrology of subsidence within that area due to WIPP excavations are not expected until several hundred years in the future (Westinghouse Electric Corporation 1994, Section 3.5).

Current Culebra hydrology field data can only intrinsically incorporate effects due to mining and other human activities that have already occurred at the time the data was collected. These data therefore cannot intrinsically incorporate the full effects of subsidence within the LWA either due to repository excavations or to mining. The effects on the Culebra of subsidence due to mining are therefore appropriately treated as multipliers of the base-case Culebra transmissivities, but the effects due to repository excavations are not treated in the same manner even though neither has yet fully occurred. EPA also observes that the occurrence of subsidence due to mining is conditional because it is uncertain whether mining will occur; however, subsidence due to WIPP excavations is not uncertain because those excavations will occur.

EPA expects that, for the CRA-2024, the screening argument for FEP W23 will be updated to either screen-in an increase in Culebra transmissivity in WIPP PA by a technically justified amount within the area affected by subsidence due to WIPP excavations, or to provide a demonstration that such an increase would have a negligible impact on the Culebra release pathway and can continue to be screened out.

EPA Reference

Westinghouse Electric Corporation 1994. Backfill Engineering Analysis Report, Waste Isolation Pilot Plant. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. ERMS 237909.

CC3-SCR-4 Supplemental Information for FEP W28 Nuclear Explosions
40 CFR § 194.32 Scope of Performance Assessments

Please supplement the screening argument for FEP W28 *Nuclear Explosions* with an evaluation of the potential for nuclear explosions in the event of a roof fall if it occurred when only a single lift of waste containers was present in a disposal room instead of the customary three lifts. Alternatively, please provide a supplemental screening argument explaining why such a scenario would be screened out of consideration in WIPP PA.

> *This FEP was screened out on the basis of low probability. In the CRA-2014 completeness review, EPA requested DOE to provide additional information on the quantities of fissile radionuclides in the inventory. The DOE responded by stating that the FEP screening was based on the lack of a rapid compression mechanism rather than the overall inventory. The CRA-2019 screening argument cites a numerical analysis of the*

effects of roof falls by Reedlunn and Bean (2019) for use in nuclear criticality evaluations. Their analyses predicted almost negligible container deformation and rearrangement from a roof fall for 7-packs of 6-inch and 12-inch Pipe Overpack containers stacked three-high in a waste panel and hence a low probability of criticality. However, the fall distance would be greater, and the dynamic impact and subsequent rapid compression would be more severe, if a roof fall occurred when only a single lift of containers had been emplaced. All credible scenarios should be evaluated when screening this FEP.

Reedlunn, B., and J. Bean. 2019. Simulations of Pipe Overpack Container Compaction at the Waste Isolation Pilot Plant. October 2019. Albuquerque, NM: Sandia National Laboratories. SAND2019-12111.

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

The rapid compaction required for a nuclear explosion is far faster and greater than a roof fall could possibly create. Nuclear weapons generate such compressive forces by detonating carefully arranged high explosives. In a carefully designed nuclear weapon, if the compressive forces are not sufficiently high or rapid, the nuclear detonation will not occur. For the Waste Isolation Pilot Plant (WIPP), the more relevant concern is whether a roof fall could cause a nuclear criticality excursion. (This is addressed in the WIPP FEP W14, Nuclear Criticality: Heat.)

As the EPA asserts, it is correct that a roof fall upon only a single lift of containers would impact with greater velocity due to the increased fall distance, provided that the falling slab was unimpeded during its descent. If we ignore the reduction of the gap between the waste and the ceiling due to room closure, and ignore the magnesium oxide sacks, which would cushion the fall, the nominal distance to the top of a three-high lift is 4.2 feet (ft) and the distance to the top of a single-high lift is 10.1 ft. Therefore, the velocity of a block of salt hitting the top of a three-high lift is 16.44 feet per second, and the impact velocity of the one-high lift stack would be 25.49 feet per second. However, because waste emplacement is random, and because of the desire to utilize disposal area as efficiently as possible, contiguous areas where only single-lift waste stacks are emplaced rarely occur. Based on observed evidence, roof falls are expected to be large slabs of salt that would likely contact adjacent two- or three-high stacks of waste prior to contacting the shorter, single lift stack, thereby impeding the descent. Nonetheless, this is still a relatively low-velocity impact and cannot cause a nuclear explosion.

The following effects tend to inhibit a nuclear explosion due to a roof fall upon a combination of one-high, two-high, and three-high waste stacks:

The uni-directional force applied by the falling slab of salt has compressive forces in a single direction. The masses of plutonium (Pu) in the pre-fall configuration are spread out and contain other materials between them. A uni-directional compressive force will at most bring several of the Pu masses closer together in a single direction while at the same time creating much opportunity for neutron leakage to greatly reduce interaction from neighboring masses. This

mass of Pu can only be critical in an ideal shape under ideal moderation. It is not possible that the compressive force of a roof fall can create this configuration.

Nuclear explosions require a perfect combination of mass, shape, neutron moderation, neutron flux and/or reflection. WIPP waste packages separate Pu masses with various container and packaging materials. The compressive forces will not on their own remove these materials from between the masses.

Although shorter stacks lead to greater roof fall distances, shorter stacks also have less Pu mass available to interact with other neighboring masses.

The potential for a nuclear explosion has been investigated previously by Rechard et al. (1996). In this study, various scenarios were evaluated that might create an atomic explosion in a radioactive waste repository. One such scenario was compression due to collapse of overlying structures, which is very similar to the postulated event presented in this comment. Due to many factors, no conceivable mechanism could be constructed that was consistent with the conditions necessary to support a nuclear explosion.

The screening argument for this FEP will be updated to address a roof fall upon various waste stack configurations in the next revision of Appendix SCR for the CRA-2024.

DOE Reference

Rechard, R., M. Tierney, L. Sanchez and M. Martell. 1996. Consideration of Criticality when Directly Disposing Highly Enriched Spent Nuclear Fuel in Unsaturated Tuff: Bounding Estimates. May 1996. Sandia National Laboratories, Albuquerque, NM. SAND96-0866. (Reference provided in Enclosure 4)

EPA Evaluation of Response

EPA accepts DOE's response that a nuclear explosion could not occur even if a roof fall occurred over a single lift of waste containers because the compressive forces would not be high enough to create the necessary compaction. In addition, DOE has committed to update this screening argument for the CRA-2024. EPA therefore finds this response to be satisfactory.

CC3-SCR-5 Supplemental Information for FEP N12 Seismic Activity
40 CFR § 194.23 Models and Computer Codes
40 CFR § 194.32 Scope of Performance Assessments

SCR-5a. Please provide justification for the screening argument statement that the range of permeabilities assigned to the DRZ is sufficiently large that it accounts for an increase due to a potential seismic event as well as other sources of uncertainty.

> *This FEP has been screened in for undisturbed performance (UP). The screening argument states that a potential impact of seismic activity on postclosure performance is increased fracturing of the DRZ around the mined entries, thereby increasing the DRZ permeability. The screening argument states that the increase due to a potential seismic event is accounted for in WIPP PA because the DRZ is treated as a zone of permanently high permeability. However, no supporting information is presented, either directly or by reference, on the range of DRZ permeabilities considered in WIPP PA, on the evidence that the range is conservatively high, on the magnitude of permeability increase that could occur from a seismic event, or whether the assigned permeability range is high enough to be bounding for all sources of uncertainty.*

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

As stated in the Compliance Certification Application (CCA) (DOE 1996), seismic events at the Waste Isolation Pilot Plant (WIPP) are not expected to have any significant effect on the mined areas of the WIPP (see CCA Chapter 2.6.2.4). However, as stated in the Agency's comment, if seismic events that were significantly greater than those analyzed were to occur, a potential result would be to increase fracturing thereby creating or increasing the disturbed rock zone (DRZ). The current representation of the DRZ within the performance assessment (PA) accounts for a wide range of uncertainty and does not take credit for the inevitability of room closure and healing of the DRZ.

Current treatment of the DRZ has changed since the CCA, where the U.S. Department of Energy (DOE) assumed a fixed permeability of 10^{-15} square meters (m^2), based on DRZ permeability studies documented in Beauheim (1996). However, in EPA's Performance Assessment Verification Test (PAVT), the EPA selected a range of $10^{-12.5}$ m^2 to $10^{-19.4}$ m^2 and justified this range in the Technical Support Document (TSD) (EPA 1998) for Section 194.23. In the TSD the EPA states that, "…[this approach] is considered by the Agency to adequately reflect both the uncertainty and the reasonable range of values for this parameter." This range is currently in use in WIPP PA.

In summary, the DOE believes that a seismic event is unlikely to create increased permeability in the DRZ. If this were to occur however, creep processes would heal these areas relatively quickly (compared to the 10,000-year performance period), such as to have little impact on long-term flow characteristics within the repository. Finally, the current treatment of the DRZ in PA is conservative and accounts for uncertainties in the creation, extent, persistence, and permeability of this repository feature.

DOE References

References with hyperlinks were provided in prior CRAs. The remainder of the reference documents will be provided in Enclosure 4 or as otherwise noted.

Beauheim, R.L. 1996. "[Salado Package #16] DRZ Permeability." Revision 1. Records Package. Sandia National Laboratories. Albuquerque, NM: ERMS 414664.

U.S. Environmental Protection Agency (EPA). 1998. Technical Support Document for Section 193.23: Parameter Justification Report. US Air Docket: V-B-14. Washington, DC: Office of Radiation and Indoor Air.

EPA Evaluation of Response to SCR-5a

The DOE's response states, in summary, that the range of uncertainty in DRZ permeability is large and conservative, and if an even greater permeability should be induced, the DRZ will heal quickly such that the impact on the long-term permeability would be small. EPA finds this response to be satisfactory.

SCR-5b. Please supplement the screening argument with a discussion of the potential impact of a seismic event on triggering roof falls and whether this impact is accounted for in WIPP PA.

> *The screening argument limits potential impacts from seismic events on postclosure performance to increases in the permeability of the DRZ around the mined entries. The shaking from seismic events could also trigger roof falls in open drifts that may change the long-term healing characteristics of those drifts. Roof falls have occurred at the WIPP in the apparent absence of seismic events. If a drift roof is on the verge of incipient collapse, a small seismic acceleration of less than 0.2G could trigger a fall.*

DOE Response (from DOE Response Package 6 (DOE RP6 2020))

Siting criteria for the WIPP included avoiding tectonic conditions that might jeopardize waste isolation over the long term, such as faulting and igneous activity, and avoiding areas where earthquake size and frequency could impact facilities and operations. The WIPP fully met both criteria (see Chapter 2.6 of the Compliance Certification Application (CCA)) (DOE 1996). Chapter 2.6.2.4 of the CCA describes the Design Basis Earthquake (DBE) used in the design of the WIPP facility. According to Pratt et al. (1979), mine experience and studies on earthquake damage to underground facilities show that tunnels are not damaged at sites having peak surface facility accelerations below 0.2 g. Sharma and Judd (1991) make similar conclusions.

For the WIPP, the DBE analysis considered a Richter magnitude 5.5 earthquake at the site, a 6.0 magnitude earthquake on the Central Basin Platform, and a 7.8 magnitude earthquake in the Basin and Range subregion. The most conservative resulting estimate of the 1,000-year acceleration at the WIPP facility was approximately 0.075 g. For additional conservatism, a peak

design acceleration of 0.1 g was selected for the WIPP DBE, which is still well below the 0.2 g value expected to cause sub-surface damage.

DOE References

The following references are included in Enclosure 4.

Pratt, H., D. Stephenson, G. Zandt, M. Bouchon and W. Hustrulid. 1979. Earthquake Damage to Underground Facilities. Proceedings of the 1979 RETC (Rapid Excavation and Tunneling Conference), Vol. 1. AIME, Littleton, CO.

Sharma, S. and W. Judd. 1991. Underground Opening Damage from Earthquakes. Elsevier Science Publishers B.V., Amsterdam. Engineering Geology 30. pp 263-276.

EPA Evaluation of Response to SCR-5b

EPA finds this response to be satisfactory. Rock falls would only impact repository performance during the postclosure period in the several hundred years before creep closure is complete. The occurrence of rock falls in the WIPP underground is uncertain even in the absence of seismic events and the likelihood that a rockfall might be seismically induced is small because of the lack of significant seismic events at and near the WIPP site and the narrow window in which it would have to occur.

CC4-SCR-6 N FEPs Updates
40 CFR § 194.32 Scope of Performance Assessments

Please update the natural FEPS with new information and confirm that screening decisions remain the same.

> *Since the CCA was submitted in 1996 and first recertified in 2004, only a handful (7) of Natural (N) FEPs appear have received any updates, and most of these updates were to eliminate individual FEPS by combining them with others or to fix errors. The only FEPS to have received regular updates are N2 Brine Reservoirs, updated in 2014 and 2019 with new GLOBAL:PBRINE parameters, and N12 Seismicity, which is periodically updated with data from the Delaware Basin Monitoring Program.*
>
> *It appears that there is no new information relating to the natural FEPS list that might be used to change, update, or even potentially strengthen screening arguments. In addition, post-CCA, DOE-funded studies directly relating to several natural FEPs are neither mentioned nor referenced in Appendix SCR. Substantial new information on the geology of the Delaware Basin has emerged from increased scientific study over the past decade in parallel with the boom of oil and gas production in the region. This information also has relevance for many Human-induced (H) events and processes. Although no changes to screening decisions are immediately apparent, EPA expects DOE to revisit the N FEPs list regularly, including for the 2024 CRA.*

One comprehensive source of updated or new information on the geology and resources of the Delaware Basin and surrounding region is the recently published two-volume compilation by the Texas Bureau of Economic Geology on the Permian Basin which is co-published as an AAPG Memoir:

Ruppel, S. C. 2019. *Anatomy of a Paleozoic Basin: The Permian Basin, USA (Vol. 1).* The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 285, AAPG Memoir 118, 399 p. doi: doi.org/10.23867/RI0285-1.

Ruppel, S. C., 2020. *Anatomy of a Paleozoic Basin: The Permian Basin, USA (Vol. 2)*. The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 285, AAPG Memoir 118, 538 p. doi:doi.org/10.23867/RI0285-2.

The following are some examples:

SCR-6a: Tectonics, Faulting FEPs

FEPs documentation is missing significant, relevant updates from the published literature for SCR-4.1.2 Tectonics: N3 Changes in Regional Stress, N4 Regional Tectonics, N5 Regional Uplift and Subsidence.

These sections rely on decades-old references and do not mention newer published studies. Even if the screening argument does not change, this suggests that DOE has neglected to stay up on relevant literature that has come out since the original certification. For example, "there are no reported stress measurements from the Delaware Basin" (pp. SCR-28) isn't completely true—there have been a number of studies reporting stress orientation measurements within and surrounding the Delaware Basin over the past decade. Several references in the current FEPs list are made to work by Zoback and colleagues in the 1980s to early 1990s, but a large body of later, more sophisticated, and widely disseminated work on regional stress states in the US, including the Worldwide Stress Map (WSM), and specific work on the Permian Basin region (e.g. Lund-Snee and Zoback, 2016, 2018) have not been incorporated into this FEP. These kinds of information are also essential for assessing seismic hazard due to induced earthquakes, and also can influence oil & gas activities.

One particular finding from the Delaware Basin is that maximum horizontal stress orientations vary from north to south. Around WIPP, maximum horizontal stress is roughly NE-SW, and the overall stress (faulting) regime is normal with a minor strike-slip component. In the middle of the Delaware Basin, it is roughly E-W, and in the south, it is roughly NW-SE. Interpreting the orientation of the NE-SW striking, ~30 Ma igneous dike identified in the early WIPP site characterization work as a paleostress indicator suggests that the overall stress field in the WIPP region has not significantly changed since that time, strengthening the claim of long term tectonic stability (tens of millions of years) and therefore the safety case for WIPP. This may also have impacts on FEPS N10, N11 (faulting).

Lund Snee, J.-E. and M. D. Zoback. 2018. State of stress in the Permian Basin, Texas and New Mexico: Implications for induced seismicity. *The Leading Edge:* 810-819.

Lund Snee, J.-E. and M. D. Zoback. 2016. "State of stress in Texas: Implications for induced seismicity." *Geophysical Research Letters,* 43(19): 10,208-210, 214.

Forand, D., et al. (2017). Constraints on Natural Fracture and In-situ Stress Trends of Unconventional Reservoirs in the Permian Basin, USA. *Proceedings of the 5th Unconventional Resources Technology Conference*. URTec 2669208.

Heidbach, O., Rajabi, M., Reiter, K., Ziegler, M., and WSM Team. 2016. *World Stress Map Database Release 2016. V. 1.1*. GFZ Data Services. http://doi.org/10.5880/WSM.2016.001

The reference discussing Quaternary Faulting (Muehlberger et al., 1978) that has been relied on since the early site characterization studies of WIPP is very dated. More recent published literature, including the USGS Quaternary Faulting Database, has identified normal faults immediately south of the southern tip of the Delaware Mountains and just outside the Delaware Basin, just over 110 km WSW from the WIPP boundary. This information may have relevance to the arguments of FEPS N10 and N11.

U.S. Geological Survey. 2018. *Quaternary fault and fold database for the United States.* https://www.usgs.gov/natural-hazards/earthquake-hazards/faults.

DOE Response (from DOE Response Package 7 (DOE RP7 2020))

It is correct that the U.S. Department of Energy (DOE) has not invested a great deal of time re-evaluating FEPs that relate to the natural system since the initial certification of the Waste Isolation Pilot Plant (WIPP). When project-derived data are relevant and available, Features, Events, and Processes (FEP) arguments are updated as appropriate. However, all evidence that DOE has collected supports the position that the tectonic/geologic environment surrounding WIPP remains stable and WIPP performs as expected. The relevant FEP screening arguments for the Compliance Certification Application (U.S. DOE 1996) remain true today for the Compliance Recertification Application (CRA)-2019. As such, the DOE concurs with the U.S. Environmental Protection Agency position that these new data do not threaten or invalidate current screening decisions. With regard to the references Ruppel (2019) and (2020), neither of these references existed prior to the data cut-off for the CRA-2019 (December 31, 2017). Nonetheless, the DOE agrees that such screening arguments may benefit from updated information in future CRAs.

DOE References

Ruppel, S. 2019. Anatomy of a Paleozoic Basin: The Permian Basin, USA (Vol. 1). The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 285, AAPG Memoir 118, 399 p. doi: doi.org/10.23867/RI0285-1.

Ruppel, S., 2020. Anatomy of a Paleozoic Basin: The Permian Basin, USA (Vol. 2). The University of Texas at Austin, Bureau of Economic Geology Report of Investigations 285, AAPG Memoir 118, 538 p. doi:doi.org/10.23867/RI0285-2.

U.S. Department of Energy. 1996. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant (October). 21 vols. Carlsbad, NM: Carlsbad Field Office. DOE/CAO-1996-2184.

EPA Evaluation of Response to SCR-6a

EPA acknowledges that some of our cited references were published after the data cut-off date of December 31, 2017, for the CRA-2019, and appreciates DOE's recognition of the benefits of maintaining FEP screening arguments based on current data. EPA expects that the screening arguments for FEPs related to the natural system will be updated for the CRA-2024 and in particular, those related to tectonics and faulting.

SCR-6b. Please update discussions of karst-related FEPs (N18, 19, 21) and manmade dissolution features (i.e. sinkholes) (H34, H59) with relevant, recent information, including an EPA-mandated, DOE-funded, SNL study.

> *Appendix SCR fails to discuss or even mention multiple recent studies on karst in the WIPP region, including what may be considered as the most comprehensive, authoritative, DOE-funded, SNL study, which was mandated and reviewed by EPA. With the exception of H59, it appears that no changes have been made to these FEPs in any way since at least CRA-2004. EPA expects reevaluation of the FEPs for each recertification cycle to determine their continued relevance, including these and related FEPs.*
>
> Lorenz, J.C. 2006a. *Assessment of the Potential for Karst in the Rustler Formation at the WIPP Site*. Albuquerque, New Mexico: Sandia National Laboratories. SAND2005-7303.
>
> Lorenz, J.C. 2006b. Assessment of the Geological Evidence for Karst in the Rustler Formation at the WIPP Site. *Caves and Karst of Southeastern New Mexico. L. Land, V.W.* pp. 243–52.
>
> *The only specific mention and discussion of these karst studies in CRA-2019 is in Appendix PA under Groundwater Flow in the Culebra (Section PA-2.1.2.6), as it was for CRA-2014, and Section 23 Computer Codes in CRA-2014. A reason for its omission in Appendix SCR is not clear.*
>
> *Additionally, EPA notes that evaporite karst in and around the Delaware Basin is still an active area of research in the scientific community. EPA regulations require that DOE track and incorporate relevant findings as appropriate, whether or not they strengthen or change the screening argument. A few examples:*
>
> Land, L. 2013. Evaporite karst in the Permian Basin region of west Texas and southeastern New Mexico: The human impact. In: *Proceedings of the 13th Sinkhole*

Conference, Carlsbad, New Mexico, 2013, Volume Sinkholes and the engineering and environmental impacts of karst. National Cave and Karst Research Institute.

Stafford, K. W., Rosales-Lagarde, L., and P.J. Boston. 2008. Castile evaporite karst potential map of the Gypsum Plain, Eddy County, New Mexico and Culberson County, Texas: A GIS methodological comparison. *Journal of Cave and Karst Studies*, v. 70, no. 1, p. 35-46.

Stafford, K. W., Nance, R., Rosales-Lagarde, L., and P.J. Boston. 2008. Epigene and Hypogene Gypsum Karst Manifestations of the Castile Formation: Eddy County, New Mexico and Culberson County, Texas. *International Journal of Speleology*, v. 37, no. 2, p. 83-98.

Stafford, K., Ehrhart, J., Majzoub, A., Shields, J., and W. Brown. 2018. Unconfined hypogene evaporite karst: West Texas and southeastern New Mexico. *USA: International Journal of Speleology*, v. 47, no. 3, p. 293-305.

DOE Response (from DOE Response Package 7 (DOE RP7 2020))

Karst remains a research topic of interest regionally as well as in the vicinity of WIPP. The Stafford references are indicative of some of the continuing research on outcrops of the Castile, albeit at considerable distance (> 40 miles) from WIPP and under hypogene conditions which do not pertain to the Castile at or near WIPP.

Lorenz (2006a, b) does provide additional insight into the discussion of dissolution. As Lorenz points out, no caves or cavernous porosity or hydrologic indications of karst have been found within the WIPP site. Therefore, it has not been considered a process of import within the land withdrawal boundaries. Lorenz brought experience and logic to the discussion of karst in the WIPP area. Several other reports regarding karst, concentrating on Nash Draw, are unreferenced; some are too recent for inclusion in CRA-2019.

Land (2013) summarizes three regional borehole collapses around wells in the Capitan aquifer mainly providing industrial water and three brine production wells. It would be appropriate to cite this and other more recent work in future updates (i.e., CRA-2024) to Appendix SCR. However, none of these six wells and sinkholes fall areally within the Delaware Basin Drilling Surveillance Program (DBDSP) boundaries.

Appendix SCR-2019, Section SCR-5.2.1.11.3.1.1 summarizes the information about sinkholes from wells over the Capitan (Wink I & II, Jal), and the original references included provide information that is the foundation for Land (2013) for these three wells. The geohydrologic setting for these three examples is not present at WIPP.

Appendix SCR-2019, Section SCR-5.2.2.4.2 summarizes information about brine wells within the DBDSP purview. Land (2013) describes the three brine well collapses, all of which are outside of the Delaware Basin. Two were shallow and were apparently too large for the overburden to support. The third (Denver City, TX) was much deeper and is not well investigated, but again, is outside the Delaware Basin and in a different geologic setting.

The conclusions for eliminating these FEPs (H34 or H59) remain the same; the effects from a brine well were considered similar to those examined (e.g., potash solution mining) in eliminating this FEP. There is no aquifer with low-salinity water below the halite intervals to use for a water supply well or for a brine well. Such drilling within the land withdrawal boundaries is prohibited during administrative control.

DOE References

Land, L. 2013. Evaporite karst in the Permian Basin region of west Texas and southeastern New Mexico: The human impact. In: Proceedings of the 13th Sinkhole Conference, Carlsbad, New Mexico, 2013, Volume Sinkholes and the engineering and environmental impacts of karst.

Lorenz, J. 2006a. Assessment of the Potential for Karst in the Rustler Formation at the WIPP Site. Albuquerque, New Mexico: Sandia National Laboratories. SAND2005-7303.

Lorenz, J. 2006b. Assessment of the Geological Evidence for Karst in the Rustler Formation at the WIPP Site. Caves and Karst of Southeastern New Mexico. L. Land, V.W. pp. 243–52.

EPA Evaluation of Response to SCR-6b

EPA considers this response to be satisfactory. DOE has adequately identified several karst-related processes and events in the region and has justified their exclusion from consideration in WIPP PA. DOE has also agreed to specifically cite the work of Lorenz (2006a, b), Land (2013), and other more recent publications in the CRA-2024.

EPA References

Land, L. 2013. Evaporite karst in the Permian Basin region of west Texas and southeastern New Mexico: The human impact. In: *Proceedings of the 13th Sinkhole Conference, Carlsbad, New Mexico, 2013, Volume Sinkholes and the engineering and environmental impacts of karst*. National Cave and Karst Research Institute.

Lorenz, J. 2006a. Assessment of the Potential for Karst in the Rustler Formation at the WIPP Site. Albuquerque, New Mexico: Sandia National Laboratories. SAND2005-7303.

Lorenz, J. 2006b. Assessment of the Geological Evidence for Karst in the Rustler Formation at the WIPP Site. Caves and Karst of Southeastern New Mexico. L. Land, V.W. pp. 243–52.

CC5-SCR-7: Effects of Cementitious Components of Repository Shaft Seals (FEPs W8 and W56)
40 CFR § 194.32 Scope of Performance Assessments

Please address how calcium ions, hydroxide ions, and isosaccharinic acid resulting from high pH effects of the cementitious materials in repository shaft seals may impact the solubilities of +III and +IV actinides. Please explain how DOE has accounted for these impacts in continuing to screen out FEPs W8 and W56 (i.e., the effects of high pH caused by cementitious materials in repository shaft seals on repository performance).

As part of the discussion of FEPs W8 Shaft Seal Chemical Composition and W56 Speciation, the effects of high pH near the cementitious repository shaft seals are screened out on the basis of beneficial consequence to the performance of the disposal system (Appendix SCR, Sections SCR-6.1.4.2.4 and SCR-6.5.2.1.3.2). The high pH caused by cementitious materials in the shaft seals was found by DOE to be beneficial to repository performance based on the assumption that high pH will lead to reduced radionuclide concentrations through changes in radionuclide speciation and sorption. However, highly alkaline conditions could increase the solubilities of +III and +IV actinides through the formation +III and +IV actinide species such as $CaAm(OH)_3^{2+}$ *and* $Ca_4Th(OH)_8^{4+}$ *(Neck et al. 2009, Altmaier et al. 2008). In addition, cellulosic materials in cementitious environments can degrade to form isosaccharinic acid (ISA) (Van Loon and Glaus 1997). ISA in repository brines could increase the solubilities of +III and +IV actinides through the formation of aqueous complexes (Gaona et al. 2008; Tasi et al. 2018).*

Altmaier, M., Neck, V. and Fanghänel, T. 2008. Solubility of Zr(IV), Th(IV) and Pu(IV) hydrous oxides in CaCl2 solutions and the formation of ternary Ca-M(IV)-OH complexes. *Radiochimica Acta* 96:541-550.

Gaona, S., Montoya, V., Colàs, E., Grivé, M., and Duro, L. 2008. Review of the complexation of tetravalent actinides by ISA and gluconate under alkaline to hyperalkaline conditions. *Journal of Contaminant Hydrology* 102:217–227.

Neck, V., Altmaier, M., Rabung, T., Lützenkirchen, J., and Fanghänel, T. 2009. Thermodynamics of trivalent actinides and neodymium in NaCl, MgCl2, and CaCl2 solutions: solubility, hydrolysis, and ternary Ca-M(III)-OH complexes. *Pure and Applied Chemistry* 81:1555-1568.

Tasi, A., Gaona, X., Fellhauer, D., Böttle, M., Rothe, J., Dardenne, K., Polly, R., Grivé, M., Colàs, E., Bruno, J., Källström, K., Altmaier, M., and Geckeis., H. 2018. Thermodynamic description of the plutonium – α-D-isosaccharinic acid system I: solubility, complexation and redox behavior. *Applied Geochemistry* 98:247–264.

Van Loon, L.R., and Glaus, M.A. 1997. Review of the kinetics of alkaline degradation of cellulose in view of its relevance for safety assessment of radioactive waste repositories. *J. Environmental Polymer Degradation* 5:97–109.

DOE Response (from DOE Response Package 9 (DOE RP9 2021))

The effect of cementitious material in repository shaft seals on repository chemistry is directly related to the amount of brine coming in contact with these materials. The potential impacts on flow and actinide/brine chemistry are both summarized below.

As described in Appendix SEAL of the Compliance Certification Application (CCA) (DOE 1996) the shaft seal system is a multi-barrier system that contains alternating layers of seal elements, which function together with the express purpose of providing engineered redundancy in the case that one (or more) of the layers suffer some sort of catastrophic failure outside of the predicted service conditions. In this way, the shaft seal system can sustain failure in certain

layers, such that the overall transport of contaminated brine from the repository and upwards through the shaft remains low and does not represent a significant contributor to overall releases.

Appendix SEAL acknowledges that certain chemical conditions could impact engineered materials. However, because of limited volumes of brine, low hydraulic gradients, and the low permeability materials employed, the geochemical setting will have little influence on shaft seal materials. By extension, the shaft seal components will have little influence on brine composition and chemistry due to the very low flow and hence limited contact of brine with these materials.

The effects of cementitious material in repository shaft seals are directly related to the amount of brine flowing through the repository shaft seals. For this reason, brine flow in the shaft seal is investigated. In the Salado Flow grid, the salt-saturated concrete monolith shaft seal ends at the bottom of the Anhydrite AB layer (Day, 2019, Figure 1); the vertical flow was evaluated at the interface between the concrete monolith and Anhydrite AB. Because vertical brine flow could be upward or downward, the integral over time of the absolute value of the flow rate was taken in order to calculate the cumulative flow. As a conservative assumption, both flow directions will be considered even though only downward flow would have the potential to interact with waste. The mean cumulative brine flow of the 100 vectors of replicate 1 for all six BRAGFLO scenarios of Compliance Recertification Application (CRA)-2019 is shown in Figure 1. A description of the six BRAGFLO scenarios can be found in Day (2019). Table 1 compares the cumulative flow in the shaft to the cumulative flow in boreholes for BRAGFLO scenarios with borehole intrusions over 10,000 years for all six BRAGFLO scenarios. In all cases with a borehole intrusion, the borehole flow is significantly greater than flow in the shaft. Mean brine flow rates in the shaft seal are very low; the cumulative brine flows between 15 and 20 m^3 gives an average brine flow rate of 0.0015 to 0.002 m^3/year. This very small amount of brine is not expected to affect brine chemistry through reaction with concrete elements of the shaft seal system.

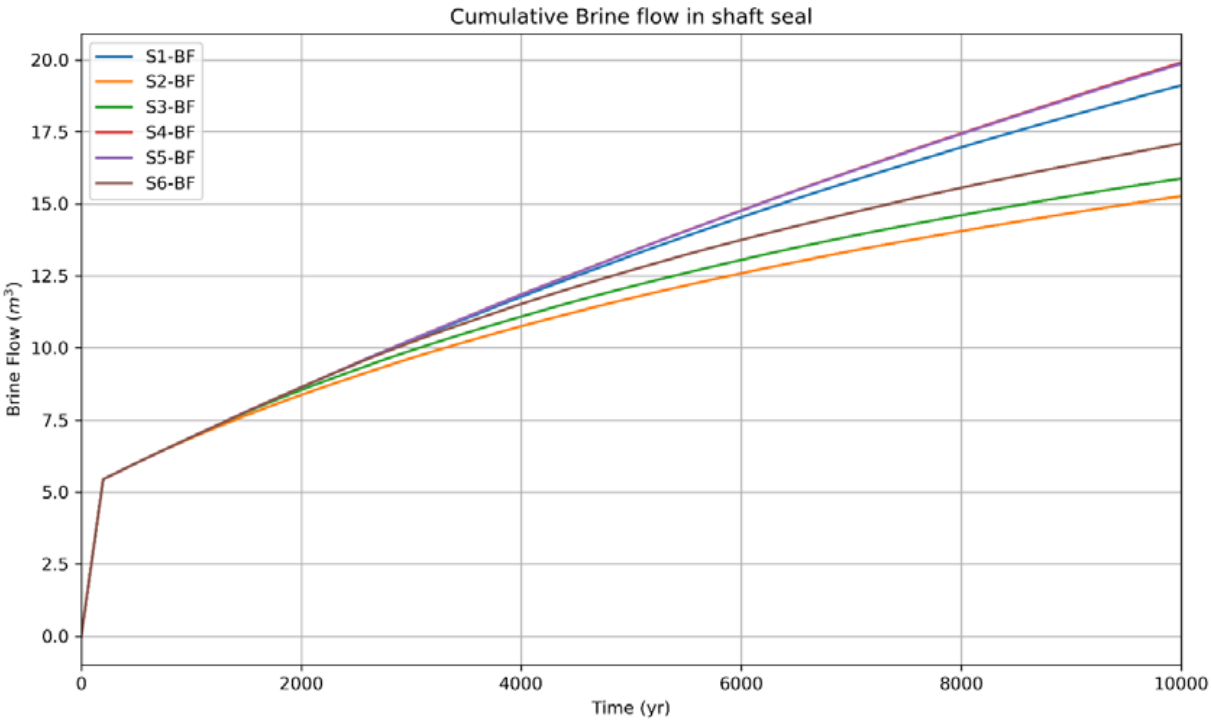


Figure 1 Replicate 1 Vector Mean Cumulative Brine Flow in the Shaft Seal

Table 1 Mean Cumulative Brine Flows

Replicate	Scenario	Brine Flow in Shaft Seal (m^3)	Brine Flow up the borehole (m^3)
1	S1-BF	19.10	N/A*
1	S2-BF	15.26	7993.58
1	S3-BF	15.88	6892.04
1	S4-BF	19.90	199.10
1	S5-BF	19.86	182.72
1	S6-BF	17.09	8083.86
2	S1-BF	18.55	N/A*
2	S2-BF	15.23	6605.13
2	S3-BF	15.71	5565.33
2	S4-BF	18.63	92.69
2	S5-BF	18.73	76.05
2	S6-BF	16.74	6634.86
3	S1-BF	18.70	N/A*
3	S2-BF	14.55	8031.25
3	S3-BF	15.21	7048.05
3	S4-BF	18.43	267.29
3	S5-BF	18.78	223.19
3	S6-BF	16.61	7876.90

*"N/A" = no flow calculated, since Scenario S1 does not represent a hypothetical intrusion borehole.

From the perspective of chemistry, the U.S. Department of Energy (DOE) continues to assert that there is not an expected or significant impact of cement on the brine and actinide chemistry in the Waste Isolation Pilot Plant (WIPP). The papers cited by the U.S. Environmental Protection Agency (EPA) are good studies that target a cement-dominated repository situation (e.g., Asse in Germany) where very high pH (pH≥13), and consequently extensive cellulose and cement degradation, is predicted. The most WIPP-relevant studies are, however, not listed in the EPA review. The important role of MgO was established in long-term (~10 year) studies performed at the Karlsruhe Institute of Technology (KIT) where it was shown that the presence of MgO greatly minimized the pH excursion otherwise observed (see Kienzler et al., 2016). Additionally, the potential impacts of gluconate and isosaccharinic acid were discussed in Appendix SOTERM, Section 3.3.3. Degradation has only been observed at pH > 12 (Mijnendonckx et al., 2020) and is not predicted to be extensive at the WIPP-relevant pH of ~ 9.4. These complexants will also not outcompete citrate and ethylenediaminetetraacetic acid (EDTA) which are already accounted for in the WIPP actinide model. For all these reasons, there is no significant impact on actinide speciation or solubility expected.

DOE References

Day, B. A. 2019. Analysis Package for Salado Flow in the 2019 Compliance Recertification Application Performance Assessment. Sandia National Laboratories. Carlsbad, NM. ERMS #571368.

Kienzler, B., C. Borkel, V. Metz, and M. Schlieker. 2016. Long-Term Interactions of Full-Scale Cemented Waste Simulates with Salt Brines. KIT Scientific Reports #7721. Karlsruhe Institute of Technology, Karlsruhe, Germany.

Mijnendonckx, K., N. Bassil, S. Nixon, A. Boylan and N. Leys. 2020. Organic materials and their microbial fate in radioactive waste, Chapter 10 in The Microbiology of Nuclear Waste Disposal. J. Lloyd and A. Cherkouk Eds. Elsevier.

EPA Evaluation of Response

EPA considers this response to be partially adequate. Calcium ions, hydroxide ions, and isosaccharinic acid resulting from highly alkaline conditions could increase the solubilities of +III and +IV actinides. The Agency requested DOE to explain how these effects were considered in concluding that high pH effects of the cementitious materials in the shaft seals will lead to reduced radionuclide concentrations and were therefore beneficial to repository performance. DOE responded that the effects of cementitious material in repository shaft seals will not be significant because of the small volume of brine flowing through the seals, that chemical conditions at the WIPP are not cement-dominated because the presence of MgO greatly minimizes pH excursions, and that degradation of cellulosic materials is not predicted to be extensive at the WIPP. The DOE response supported a screening conclusion of low consequence but did not support a conclusion of beneficial. The DOE's screening arguments for these FEPs should be reworded accordingly.

CC5-SCR-8: Screening Argument for Galvanic Coupling within the Repository (FEP W50) 40 CFR § 194.32 Scope of Performance Assessments

Please indicate whether galvanic coupling between iron and lead in WIPP waste and packaging materials can continue to be screened out of WIPP PA despite the increased lead inventory in the CRA-2019 DPA. What are the effects of the reported galvanic corrosion of lead by iron oxides and hydroxides on the screening argument for FEP W50 Galvanic Coupling (within the repository)?

> *The screening argument for excluding galvanic coupling from the WIPP PA is based on the preponderance of iron over other metals within the repository and the likely passivation of many nonferrous metals [FEP W50 Galvanic Coupling (within the repository), Appendix SCR, Section SCR-6.5.1.5.3]. The lead inventory has greatly increased for the CRA-2019 DPA, with the ratio of lead packaging materials to the iron inventory now greater than 1:5 (0.22, see table below). The proportion of lead to iron in panels filled after December 2011 will be higher than this percentage, because only a single shielded container was placed in the repository as of the CRA-2014 inventory cutoff date (December 31, 2011, Franco 2015). The Agency previously evaluated the available lead corrosion data for WIPP brines (Roselle 2013) and found that lead surface passivation was not demonstrated (EPA 2017), so lead passivation cannot be assumed to prevent galvanic corrosion.*

Recent studies have indicated that iron oxides and hydroxides, such as those formed by anoxic corrosion in the WIPP repository, may cause galvanic corrosion of lead (Trueman and Gagnon 2016, Trueman et al. 2017). There is also evidence that humic acids and natural organic matter, which will be present in waste soils in the repository, may prevent surface passivation of lead (Korshin et al. 2000, Lin and Valentine 2008, Trueman et al. 2017). Consequently, the possible influence of these materials on galvanic corrosion within the repository should be addressed in the screening argument.

WIPP Iron-Based Metals and Lead Inventories (Van Soest 2018)

Metal	Inventory
Iron-based metals and alloys, CH and RH waste (kg)	1.54×10^7
Steel packaging materials, CH and RH waste (kg)	4.77×10^7
Total Iron and Steel (kg)	6.31×10^7
Lead packaging materials, RH waste	1.38×10^7
Lead packaging materials (kg) /Total iron and steel (kg)	0.219

EPA (United States Environmental Protection Agency). 2017. *Technical Support Document For Section 194.24, Evaluation Of The Compliance Recertification Actinide Source Term, Gas Generation, Backfill Efficacy, Water Balance And Culebra Dolomite Distribution Coefficient Values*. Office of Radiation and Indoor Air, Washington, D.C., EPA-HQ-OAR-2014-0609, June 2017.

Franco, J.R. 2015. *Response to Environmental Protection Agency Letter Dated December 17, 2014 Regarding the 2014 Compliance Recertification Application. U.S. Department of Energy Letter to J.D. Edwards*, U.S. Environmental Protection Agency, March 18, 2015.

Korshin, G.V., Ferguson, J.F., and Lancaster, A.N. 2000. Influence of natural organic matter on the corrosion of leaded brass in potable water. *Corrosion Science* 42:53-66.

Lin, Y.-P., and Valentine, R.L. 2008. The release of lead from the reduction of lead oxide (PbO2) by natural organic matter. *Environmental Science and Technology* 42:760-765.

Roselle, G.T. 2013. *Determination of Corrosion Rates from Iron/Lead Corrosion Experiments to be used for Gas Generation Calculations, Revision 1. Analysis Report*, Sandia National Laboratories, Carlsbad, New Mexico, ERMS 559077.

Trueman, B.F., and Gagnon, G.A. 2016. Understanding the role of particulate iron in lead release to drinking water. *Environmental Science and Technology* 50:9053-9060.

Trueman, B.F., Sweet, G.A., Harding, M.D., Estabrook, H., Bishop, D.P., and Gagnon, G.A. 2017. Galvanic corrosion of lead by iron (oxyhydr)oxides: potential impacts on drinking water quality. *Environmental Science and Technology* 51:6812-6820.

DOE Response (from DOE Response Package 10 (DOE RP10 2021))

The U.S Environmental Protection Agency's (EPA) argument is that galvanic coupling between iron oxides and lead could enhance the lead oxidation rate in the repository. The EPA's premise

that iron oxides could participate in galvanic coupling to lead in the WIPP repository is at least in part based on cited recent articles written by B. F. Trueman and G. A. Gagnon *(Trueman and Gagnon 2016, Trueman et al. 2017)*.

The U.S Department of Energy (DOE) does not dispute the idea that galvanic corrosion is possible in the repository. The underlying thermodynamics of lead oxidation by the reduction of ferrous and mixed ferrous-ferric compounds are fairly well understood. If anoxic galvanic corrosion between ferrous hydroxide and lead were to occur, reducing iron and oxidizing lead, we hypothesize that the total moles of gas generated would be bounded from above by the equivalent non-galvanic corrosion of lead; the rate of lead corrosion could be affected, however. We would also hypothesize that little-to-no additional gas generation would occur through reactions similar to

$$Pb + Fe(OH)_2 \leftrightarrow PbO + Fe + H_2O \quad (1)$$

It's unclear if reaction (1) would have any impact on repository performance. Regardless, for the reasons given in the paragraphs below, the detailed physics and impact of galvanic corrosion in the WIPP repository remain speculative due to the lack of relevant studies performed under WIPP-relevant conditions. Therefore, until information indicating that this effect could be important is obtained, DOE believes this effect should remain excluded and also believes that there is insufficient relevant information to include the potential impacts of galvanic corrosion between lead and iron on repository performance.

It is known that some ferrous compounds can participate readily in galvanic reactions. The classic example is pyrite, a component in primary lithium-ion batteries, being capable of carrying significant electron energy density (Zou et al. 2020). Pyrite's ability to participate in galvanic reactions has been studied for decades (Fong et al. 1989); formation of ferrous sulfides in the repository remains a subject of ongoing study (Brush and Xiong 2014) and were not included in the Compliance Recertification Application (CRA)-2019 (U.S. DOE 2019, Appendix GEOCHEM, Section GEOCHEM-2.1.6). There are also a limited number of studies on the anoxic coupling of magnetite and steel under anoxic conditions (Fushimi et al. 2002; Al-Mayouf et al. 2007; Robineau et al. 2017). The number of studies on galvanic coupling between ferrous compounds (ferrous hydroxides and carbonates) and metallic lead under anoxic conditions appears to be small. DOE has reviewed the journal articles by Trueman and Gagnon (Trueman and Gagnon 2016, Trueman et al. 2017) and does not agree that the experimental conditions used in these articles are completely relevant to the Waste Isolation Pilot Plant (WIPP) repository conditions; these articles are most relevant to municipal water systems where ppm levels of dissolved lead via galvanic corrosion are of concern. DOE's specific rationale for this position is given below.

First consider the Trueman et al. (2017) article. The phases considered in this article include magnetite, hematite, and a "field-extracted iron-corrosion scale" (of undisclosed origin) that contained magnetite and goethite. Currently only ferrous iron phases (e.g. $Fe(OH)_2$ and $Fe_2Cl(OH)_3$) are directly included in the Performance Assessment (PA). No fully oxidized (ferric) iron compounds are directly included (U.S. DOE 2019, Appendix GEOCHEM, Section GEOCHEM-2.1.3) as the repository is assumed to be under reducing conditions post closure. Magnetite is considered in WIPP PA (U.S. DOE 2019, Appendix GEOCHEM, Section

GEOCHEM-2.2.1), however it remains uncertain whether magnetite will form in significant amounts in the repository during the 10,000 year regulatory period (U.S. DOE 2019, Appendix GEOCHEM, Sections GEOCHEM-2.2.1, GEOCHEM-3.2.1.3). Furthermore, it is also DOE's opinion that the experimental conditions used in the Trueman et al. (2017) paper are not consistent with those expected in the WIPP repository. The Trueman experiment was conducted under oxic conditions (WIPP is expected to be anoxic). The electrolyte fluid composition used in the Trueman paper was 60 mg/L $NaHCO_3$ (WIPP is expected to be nearly saturated brine).

Another concern with the Trueman et al. (2017) article is that no time series was presented for the current or voltage to determine if the reaction rate remained constant or decayed with time. A relevant paper illustrating this concern is Robineau et al. (2017). In this paper a galvanic cell was constructed using magnetite and steel under anoxic conditions. The ionic strength in this paper was also low (0.01 mol/L NaCl + 0.01 mol/L $NaHCO_3$). The current generated during the experiment, shown in Figure 7 of the Robineau et al. (2017) article, begins at ≈ 60 μA/cm2 but decays in some experiments to low values after 80 days, showing that galvanic corrosion rates decreased with time.

Pertaining to the question of whether galvanic corrosion can be sustained over long periods of time, the DOE also has concerns with the way electrical contact is constructed in many of the cited experiments. In the Trueman et al. (2017) article, the iron oxides used were pressed into a cathode at 60 MPa in a spark plasma sintering instrument. The cathode was then further treated at 525 °C. We assume the authors of this paper required the high-force high-temperature conditions to obtain sufficient electrical contact between the cathode and the copper conductor used. It's unclear how WIPP would provide similar conditions for electrical contact, how galvanic corrosion rates would be affected with poorer electrical contact, and how the rate would change as electrical contact degrades over the 10,000 year regulatory period.

Similar concerns arise when examining the Trueman and Gagnon (2016) article. The section of this article relevant to EPA's question is Galvanic Corrosion of Lead by Magnetite. The concerns given in the paragraph above apply to this article as well. Furthermore, the article itself demonstrates a low correlation between galvanic current and lead release, *"Galvanic current and lead release were moderately correlated (R2 = 0.53): a strong correlation between current and lead release was neither observed nor expected due to the formation of corrosion scale on lead coupons."*

In conclusion, based on the lack of WIPP-relevant information demonstrating that this effect could be important, it is DOE's opinion that galvanic coupling between lead and ferrous iron should continue to be excluded and that there is insufficient information to determine, without excessive speculation, the impact on PA.

DOE References

Al-Mayouf, A., N. Al-Mobarak, and A. Al-Swayih. 2007. Dissolution of Magnetite Coupled with Iron of Various Surface Areas. Corrosion 63(10): 916-923.

Brush, L. and Y. Xiong. 2014. Test Plan 14-05; Test Plan for the Experimental Determination of The Solubilities of Iron and Lead in the Presense of Dissolved Hydrogen Sulfide Species. Albuquerque, NM, Sandia National Laboratories. ERMS 562861

Fong, R., J. Dahn, and C. H. W. Jones. 1989. Electrochemistry of Pyrite-Based Cathodes For Ambient-Temperature Lithium Batteries. Journal of the Electrochemical Society 136(11): 3206-3210.

Fushimi, K., T. Yamamuro, and M. Seo. 2002. Hydrogen Generation from a Single Crystal Magnetite Coupled Galvanically with a Carbon Steel in Sulfate Solution. Corrosion Science 44: 611-623.

Robineau, M., A. Romaine, R. Sabot, M. Jeannin, V. Deydier, and S. Necib. 2017. Galvanic Corrosion of Carbon Steel in Anoxic Conditions at 80 C associated with a heterogeneous magnetite (Fe3O4)/mackinawite (FeS) layer. Electrochimica Acta 255: 274-285.

Zou, J., J. Zhao, B. Wang, S. Chen, P. Chen, Q. Ran, L. Li, X. Wang, J. Yao, H. Li, J. Huang, X. Niu, and L. Wang. 2020. Unraveling the Reaction Mechanism of FeS2 as a Li-Ion Battery Cathode. ACS Applied Materials & Interfaces 12(40): 44850-44857.

EPA Evaluation of Response

Galvanic coupling can result in more rapid gas generation from accelerated corrosion of the anodic metal. Galvanic coupling within the repository has been screened out from WIPP PA based on the preponderance of iron over other metals in the repository. In this completeness comment the Agency requested that DOE determine whether galvanic coupling between iron and lead in WIPP waste and packaging materials can continue to be screened out despite the increased lead inventory in the CRA-2019 PA. EPA also asked that DOE provide additional information regarding the possible effects on the screening argument of potential galvanic corrosion of lead by iron oxides and hydroxides within the repository.

DOE responded by hypothesizing that the total moles of gas generated would be bounded by the equivalent non-galvanic corrosion of lead but that galvanic coupling could increase the rate of lead corrosion and therefore also the rate of gas generation. DOE hypothesized that little-to-no increase in the volume of gas generation would occur due to galvanic coupling but there is a lack of WIPP-relevant information demonstrating that galvanic coupling could be important to repository performance. DOE stated that there is insufficient information to determine the impact of galvanic coupling on WIPP PA but it is their opinion that galvanic coupling between lead and ferrous iron may have little influence on gas generation rates. DOE concluded that this process should continue to be excluded from WIPP PA.

EPA concurs that there is currently no evidence that galvanic corrosion will be a significant process in the WIPP repository and that any increase in the volume of gas generated is likely to be small. However, the current screening argument for this FEP relies on the preponderance of iron in the inventory. It does not address the much larger lead inventory introduced in CRA-2019 by increased use of shielded containers, and it does not emphasize that galvanic coupling would not significantly affect gas generation. It is also unclear from site-specific lead corrosion experiments that lead surfaces will be passivated in the repository. EPA expects that the screening argument for this FEP will be updated for CRA-2024 to address the larger lead inventory and the effects of potential increases in galvanic coupling.

CC5-SCR-9: Screening Decision for Gas Generation by Lead Corrosion (FEPs W5 and W49)
40 CFR § 194.23 Models and Computer Codes

Please calculate the gas generated by lead corrosion under inundated conditions for time periods up to 10,000 years using a lead corrosion rate of 6.79 × 10-15 m/sec (see below), the mass of lead in the CRA-2019 DPA inventory (1.38 × 107 kg, Van Soest 2018), and the expected lead surface area per kg in the WIPP inventory and packaging materials. Please compare the results of these lead corrosion gas-generation calculations to equivalent calculations for inundated iron corrosion using the mean inundated steel corrosion rate, iron inventory, and iron surface area per kg used in the CRA-2019 DPA.

> *The screening arguments for FEP W5 Container Material Inventory and FEP W49 Gases from Metal Corrosion state that gas generation from lead corrosion is not included in the CRA-2019 DPA calculations based on an assessment by Kirkes (2019). Kirkes (2019) evaluated WIPP lead corrosion rate data (Roselle 2013) and cited concerns about the data related to the difficulty of removing cleaning and rinse solutions from the lead coupons because of their surface porosity, mass loss from the coupons during cleaning, and limited data from experiments with fully submerged lead coupons.*
>
> *Roselle (2013) acknowledged that the porosity of the lead coupons made complete removal of cleaning and rinse solutions difficult and resulted in more weight loss data variability for lead corrosion experiments than for steel corrosion experiments. However, the variation observed in the experiments is included in the calculated uncertainties for the lead corrosion rates. Mass loss during cleaning was accounted for using a graphical procedure (Roselle 2013, Section 3.5). Although the relatively soft lead metal may have been affected by base metal loss during cleaning, no evidence was presented by Kirkes (2019) to indicate that the corrections carried out by Roselle (2013) were insufficient. EPA (2017) previously evaluated the information presented by Roselle (2013) and concluded that the methods used by Roselle (2013) to account for material loss during cleaning were adequate.*
>
> *Kirkes (2019) stated that "After further consideration, it was decided that only the fully submerged coupons should have been used for the calculations rather than an average of the partially and fully submerged coupons." However, no justification was provided for this decision. The statement by Kirkes (2019) eliminating partially submerged coupon data from consideration is problematic because iron corrosion data from partially submerged and fully submerged coupons were used to calculate inundated gas generation rates for the CRA-2014 PA and CRA-2019 DPA (Zeitler and Hansen 2015, Zeitler 2018).*
>
> *Kirkes (2019) contended that removing partially submerged coupon data from the lead corrosion data set results in only one or two non-negative mass loss values at each time interval. This is inconsistent with the fully submerged coupon data reported by Roselle (2013, Table A-2). For each time period and $CO_2(g)$ concentration, mass loss data were obtained from 8 samples (2 coupons × 2 brines × 2 presence/absence of organics).*

Including both the 0 ppm and 350 ppm CO_2 data that bracket modeled WIPP conditions, yields 16 samples per time period. Positive mass loss measurements are available for 15 fully submerged samples for each of the 6-month, 12-month, and 18-month time periods and positive mass loss measurements are available for 14 fully submerged samples for the 24-month time period.

Kirkes (2019) maintains that the Roselle (2013) lead corrosion rate data indicate likely passivation of the lead surface. EPA (2017) previously evaluated the information presented by Roselle (2013) and found that the results of the experiments with coupons partially or fully submerged in brine did not conclusively demonstrate surface passivation of lead. Because it is possible that processes such as galvanic coupling between iron and iron oxides and lead (Trueman and Gagnon 2016, Trueman et al.2017) or dissolution of lead oxide surface coatings by natural organic matter or humic acid may occur (Korshin et al. 2000, Lin and Valentine 2008, Trueman et al. 2017), there is insufficient evidence to demonstrate lead surface passivation for WIPP PA.

The screening arguments for excluding lead corrosion from gas generation would be considerably strengthened by assessing the magnitude of gas generation by anoxic lead corrosion under inundated conditions. Gas generation rates from lead corrosion under humid conditions are less likely to be important to WIPP PA because humid rates are significantly less than inundated rates (see table below) and surface passivation of lead under humid conditions appears more likely to occur under repository conditions.

If the approach used to develop the inundated steel corrosion rate (Zeitler and Hansen 2015) for the CRA-2014 is used to develop an inundated lead corrosion rate from the Roselle (2013) data, 120 samples are available (119 positive rate measurements plus an additional value of 0 m/sec added to the data set). This data set includes 0 ppm and 350 ppm CO2(g) concentrations, partially submerged and fully submerged samples, both GWB and ERDA-6 brines, presence and absence of organics, and all experimental durations (6, 12, 18 and 24 months). The mean lead corrosion rate is 6.79 × 10-15 m/sec, which is approximately equal to the mean steel corrosion rate measured at atmospheric pressure (Zeitler and Hansen 2015). Because the calculated lead corrosion rate is similar in magnitude to the steel corrosion rate and the current lead inventory is a significant fraction of the iron inventory, screening calculations should be performed to compare the gas generation rates from inundated steel and lead corrosion.

Average Corrosion Rates (μm/yr) for Lead Samples Averaged over all Time Segments		
	CO_2 Concentration (ppm)	
Brine	0	350
GWB	0.285 ± 0.21	0.210 ± 0.17
GWB org	0.247 ± 0.18	0.188 ± 0.11
ERDA-6	0.239 ± 0.20	0.137 ± 0.07
ERD-6 org	0.238 ± 0.18	0.178 ± 0.13
Humid	0.053 ± 0.05	0.053 ± 0.03

Roselle (2013) Table 10

EPA (United States Environmental Protection Agency). 2017. *Technical Support Document For Section 194.24, Evaluation Of The Compliance Recertification Actinide Source Term, Gas Generation, Backfill Efficacy, Water Balance And Culebra Dolomite Distribution Coefficient Values*. Office of Radiation and Indoor Air, Washington, D.C., EPA-HQ-OAR-2014-0609, June 2017.

Kicker, D.C, and Herrick, C.G. 2013. *Parameter Summary Report for the Compliance Recertification Application, Rev. 0*. Sandia National Laboratories, ERMS 560298.

Kim, S., and Feng, L.M. 2019. *Parameter Report for the 2019 Compliance Recertification Application Performance Assessment (CRA-2019 PA), Rev. 0*. Sandia National Laboratories, ERMS 571377.

Kirkes, L. 2019. *Lead Inventory Impact on Gas Generation*. Sandia National Laboratories. Carlsbad, New Mexico, ERMS 571255.

Korshin, G.V., Ferguson, J.F., and Lancaster, A.N. 2000. Influence of natural organic matter on the corrosion of leaded brass in potable water. *Corrosion Science* 42:53-66.

Lin, Y.-P., and Valentine, R.L. 2008. The release of lead from the reduction of lead oxide (PbO2) by natural organic matter. *Environmental Science and Technology* 42:760-765.

Roselle, G.T. 2013. *Determination of Corrosion Rates from Iron/Lead Corrosion Experiments to be Used for Gas Generation Calculations, Revision 1. Analysis Report*, Sandia National Laboratories, Carlsbad, New Mexico, ERMS 559077.

Telander, M.R., and Westerman, R.E. 1997. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments*. SAND96-2538, Prepared for Sandia National Laboratories, Albuquerque, New Mexico by Pacific Northwest National Laboratory, Richland, Washington.

Trueman, B.F., and Gagnon, G.A. 2016. Understanding the role of particulate iron in lead release to drinking water. *Environmental Science and Technology* 50:9053-9060.

Trueman, B.F., G.A. Sweet, M.D. Harding, H. Estabrook, D.P. Bishop, and G.A. Gagnon. 2017. Galvanic corrosion of lead by iron (oxyhydr)oxides: potential impacts on drinking water quality. *Environmental Science and Technology* 51:6812-6820.

Zeitler, T.R. 2018. *Cumulative distribution for STEEL:CORRMCO2 for the CRA-2019 PA.* Sandia National Laboratories, Carlsbad, New Mexico, ERMS 570869.

DOE Response (from DOE Response Package 10 (DOE R10 2021))

Surface Area of Lead Calculation

Using the mass of lead in the WIPP inventory of 1.38 X 10^7 kg (Van Soest, 2018), and the density of lead of 11,340 kg/m^3; the volume of lead in the WIPP inventory is 1216.9 m^3. With all of the lead inventory coming to WIPP in the form of remote-handled (RH) packaging material, it is assumed all lead has a similar volume to surface area ratio as the lead in the RH shielded containers. For this calculation of lead surface area, we assume all shielded containers possess a 1-inch-thick lead shielding sandwiched between a double-walled steel shell (see Figure 1 below).

For this analysis, it will be assumed that none of the encasing steel shells inhibits lead corrosion. A shielded container has a height of 35.75 inches (0.9070 m) and an outer diameter of 23 inches (0.5842 m) (Table Data-B-5, Appendix-DATA, U.S.DOE 2014). Assuming the lid and base of the shielded containers is ¾ of an inch (0.0190 m), the lead lining of a shielded container would have an outer radius of 0.2921 m, an inner radius of 0.2667 m and a height of 0.871 m. The lead in the annulus of each container would have a volume of 0.0388 m^3 and a surface area of 3.147 m^2. Note that this surface area includes both the inside and outside surfaces of the 1 inch thick lead lining, as well as the 1 inch circumferential surfaces at the top and bottom of the lead lining. The total surface area of all the lead can then be found as the surface area of a container multiplied by the total lead volume divided by the container lead volume.

$$A_s = A_c * \frac{V_T}{V_c} = 98{,}681.7\ m^2 \qquad (1)$$

Where:

A_s = Total Surface Area of Lead in Repository

A_c = Surface Area of Lead in a Shielded Container (3.147 m^2)

V_T = Total Volume of Lead in Repository (1216.9 m^3)

V_c = Volume of Lead in a shielded container (0.0388 m^3)

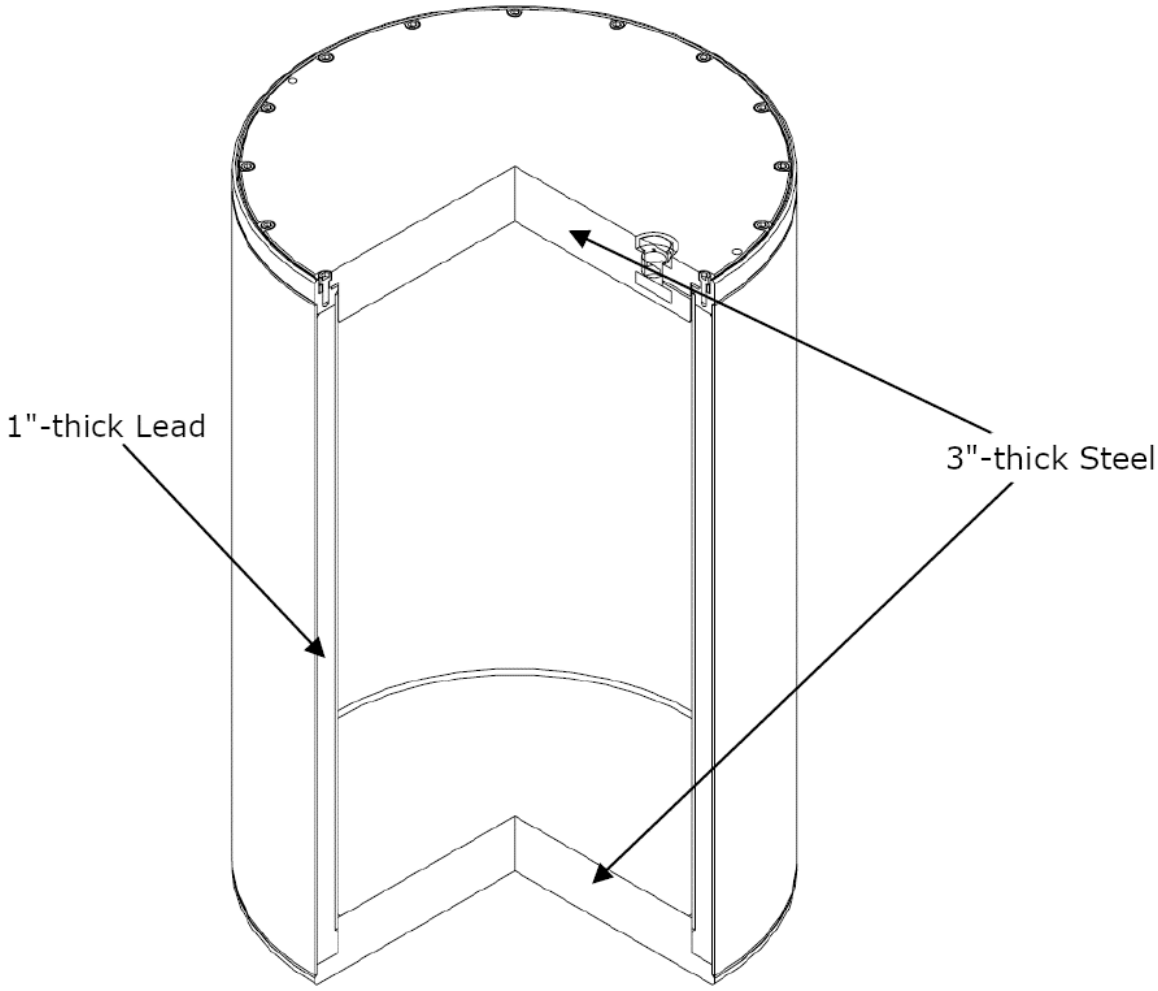


Figure 1. Isometric Exposed View of the Shielded Container (Modified from Dunagan et al. 2007)

Calculation of Gas Generation Reaction Rate

The general reaction for the corrosion of inundated lead is:

$$Pb(s) + H_2O(l) \rightarrow PbO(s) + H_2(g) \quad (2)$$

It is assumed that lead corrosion reaction rates are zeroth order (constant). The stoichiometric coefficient for hydrogen generation from this reaction is 1.

Using the EPA-specified corrosion rate of 6.79 X 10^{-15} m/sec, the gas generation reaction rate in units of mol/(m^3 sec) is calculated as:

$$G_{rate,Pb} = \frac{r\,\rho}{M_w}\frac{A_s}{V_{repos}} = 8.36 \times 10^{-11} \quad (2)$$

Where:

$G_{rate,Pb}$ = Gas generation reaction rate in $\frac{mol}{m^3 sec}$

r = Lead corrosion rate (6.79 X 10^{-15} m/sec)

ρ = Density of Lead (11,340 kg/m^3)

M_w = Molecular Weight of Lead (0.2072 kg/mol)

A_s = Total Surface Area of Lead in Repository (98681.7 m^2)

V_{repos} =Volume of the repository (PA parameter REFCON:VREPOS = 438406.08 m^3)

The gas generation reaction rate is used to calculate a gas generation rate (mol/s) for a given volume after elapsed time τ as:

$$G(\tau) = G_{rate,Pb} * S_w(\tau) * V \quad (3)$$

Where

S_w =The brine saturation in the Volume

V = The volume in m^3

τ = Post-closure time (0 – 10,000 years in units of seconds)

The cumulative amount of gas generated, in moles, over the elapsed time t is given by:

$$L_G(t) = \int_0^t G(\tau)\,d\tau \quad (4)$$

The DOE performed a bounding calculation using brine saturations on a grid-cell basis and waste area grid cell volumes over the 10,000-year BRAGFLO simulations for the CRA-2019 analysis. This calculation is bounding as a fully-coupled reaction would consume brine, lowering the brine saturation, thus lowering future gas generation.

Results

The mean gas generation from lead corrosion over time for the 100 vectors of replicate 1 of CRA-2019 was compared to the other gas generation mechanisms currently used in the Performance Assessment (PA) calculations. The cumulative gas generations are plotted in Figure 2 for four representative scenarios. A complete description of the BRAGFLO scenarios is presented by Day (2019). Table 1 shows the gas generated from lead corrosion, the total gas

generated from existing mechanisms in the PA calculation, and the percent of the additional gas that lead corrosion would contribute to the system. The calculation shows the potential lead corrosion would contribute less than 0.5% to the total gas generation in the system. Other CRA-2019 completeness responses (CC3-GEOCHEM-19b) have shown the PA results are not changed by much larger additional gas generation than the lead corrosion reaction provided here. Also, other completeness responses (CC3-GEOCHEM-17b), have shown that increasing gas generation reaction that consume brine, such as lead corrosion, would lower the mean total releases. Thus, the omission of lead corrosion could be considered conservative with respect to mean total releases.

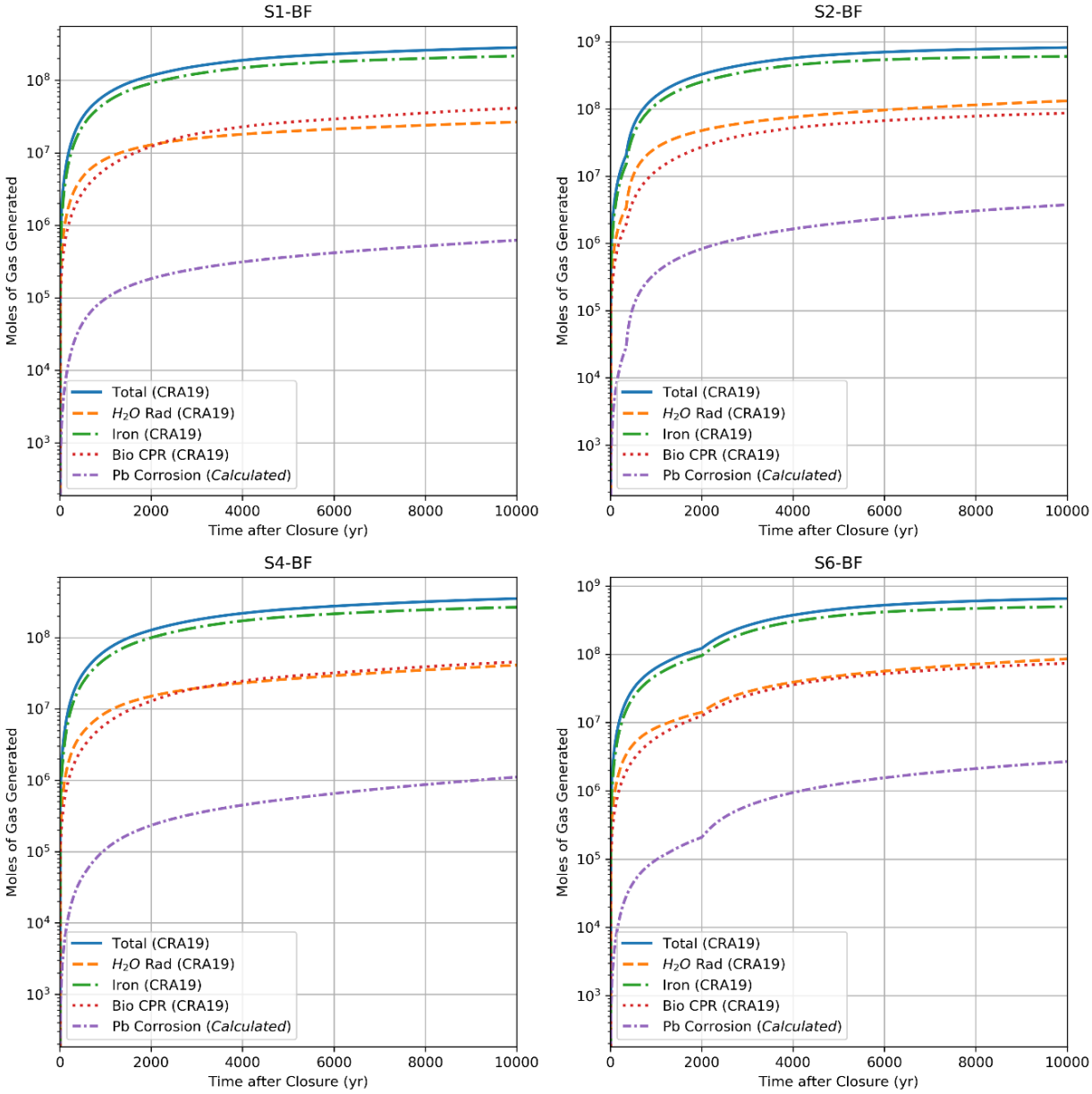


Figure 2. Comparison of Gas Generation Sources over Time

Table 1 Gas Generation

BRAGFLO Scenario	Lead Corrosion Cumulative Gas Generated (mols H_2)	Total PA Cumulative Gas Generated (mols H_2) (Iron Corrosion + Biodegradation + Brine Radiolysis)	Amount of gas generation from lead as a percent of total PA gas generation
S1-BF	6.22E+05	2.83E+08	0.22%
S2-BF	3.76E+06	8.21E+08	0.46%
S3-BF	3.19E+06	7.61E+08	0.42%
S4-BF	1.11E+06	3.53E+08	0.31%
S5-BF	1.06E+06	3.49E+08	0.30%
S6-BF	2.68E+06	6.55E+08	0.41%

Conclusions

As shown by the above analysis, there is very little gas generated by this conservative model of lead corrosion. Therefore, the DOE position continues to be that a gas generation model based on lead corrosion is not needed in WIPP PA. When using the EPA-directed lead corrosion rates and applying reasonable assumptions about surface area, a very low relative contribution to the currently estimated quantity of gas generation in the WIPP was shown. While features, events, or processes (FEP) W49 (Gases from Metal Corrosion) (primarily iron) is accounted for in performance calculations, gases from the lead inventory can continue to be omitted from performance calculations, as they do not represent a meaningful fraction of the gas production caused by iron corrosion, or the overall gas production by all gas generating processes.

DOE References

Day, B. 2019. Analysis Package for Salado Flow in the 2019 Compliance Recertification Application Performance Assessment (CRA-2019 PA). Sandia National Laboratories. Carlsbad, NM. ERMS 571368.

Dunagan, S., G. Roselle, E. Vugrin, and J. Long. 2007. Analysis Report for the Shielded Container Performance Assessment (Revision 1.0). Sandia National Laboratories. Carlsbad, NM. ERMS 547358.

U.S. DOE. 2014. Title 40 CFR Part 191 Compliance Recertification Application for Waste Isolation Pilot Plant (March). Carlsbad Field Office. Carlsbad, NM. DOE/WIPP 2014-3503.

Van Soest, G.D. 2018. Performance Assessment Inventory Report – 2018. Los Alamos National Laboratory Carlsbad Operations. Carlsbad, NM. LA-UR-18-31882.

EPA Evaluation of Response

EPA requested that DOE perform additional calculations using a mean lead corrosion rate of 6.79×10^{-15} m/s provided by the Agency and reasonable assumptions about surface area to support the assertion that lead corrosion would be an insignificant contributor to gas generation in the WIPP repository. The results demonstrated that gas generation from lead corrosion would be a negligible fraction of overall gas generation rates due to the higher surface area and higher mean corrosion rate of steel (1.33×10^{-14} m/sec). EPA therefore concurs with DOE's conclusion that gases generated from corrosion of the lead inventory can continue to be omitted from performance calculations.

CC5-SCR-10: N FEPs and Related Updates
40 CFR § 194.32 Scope of Performance Assessments

Please update the natural FEPS with newer information and confirm that screening decisions remain the same.

> *Since the CCA was submitted in 1996 and first recertified in 2004, few Natural (N) FEPs appear to have received any updates. In addition, related Human-induced FEPs may need to likewise be updated and screening decisions reviewed.*

SCR-10a. Natural gas intrusion (N32)

> *The description seems to imply that natural gas is only produced in the Morrow Formation, 6000+ feet below the WIPP repository. In fact, most of the hydrocarbon bearing formations below WIPP are overpressured and produce considerable amounts of gas in addition to oil, including the Delaware Mountain Group that directly underlies the Ochoan series of evaporites. See Table 4 in Hall and Melzer (2018). The update to this FEP may be completed as part of CRA-2024 because migration is still likely very low probability under natural conditions, and screening conditions likely will not change. Additionally, information in Human-Induced Geological EPs: Drilling (SCR-5.1.1.1.3) should be similarly updated/expanded.*

Hall, R. K., and Melzer, S. L., 2018, *Water Injection in WIPP Vicinity: Current Practices, Failure Rates and Future Operations*. Russell K. Hall and Associates, Incorporated. Midland, Texas. August.

DOE Response (from DOE Response Package 10 (DOE R10 2021))

All FEPs within the WIPP FEPs baseline are subject to update at each recertification cycle. Those FEPs that merit change will be re-evaluated as appropriate.

EPA Evaluation of Response to SCR-10a

The DOE response was inadequate. The Agency understands that the entire FEP baseline is subject to update and reevaluation at each recertification cycle. EPA's concern is not with the

protocols of DOE's FEP baseline reviews, which are appropriate, but rather with inadequate demonstrations and/or documentation that those protocols are being diligently followed. This EPA comment uses FEP N32 as an example of a screening argument that is based only on 25-year old information from the CCA and concerns a resource that is much more widely distributed than described. EPA cited Hall and Melzer (2018) as an example of a compilation of updated information of the type that DOE collects as part of its Delaware Basin Monitoring Program. EPA expects that this additional information is unlikely to change the screening decision regarding the natural gas resource and it is therefore appropriate for DOE to update the factual basis for this FEP as part of the CRA-2024. However, when seen as part of the broader issue of timely updates to the natural and human-induced FEP screening arguments, EPA expects DOE to demonstrate a continuing awareness of new information on features, events, and processes relevant to WIPP performance and include them in the screening arguments either directly or by reference, whether or not they affect the screening decision.

SCR-10b. Groundwater characteristics (N23, N24, N26, N27)

> *The existing discussion on groundwater flow is very limited and refers to the CCA (1996). It fails to mention the subsequent work that has been done on shallow groundwater in and around WIPP, especially on the Culebra and its hydrogeologic properties. This section should be updated to summarize and include more recent work, briefly explain how these FEPs are incorporated into PA calculations, and reference where a more complete discussion on PA calculations can be found. This may be addressed in conjunction with the related comments previously submitted such as CC3-HYDRO-5.*

DOE Response (from DOE Response Package 10 (DOE RP10 2021))

Appendix SCR historically presents the screening arguments and screening decisions for WIPP features, events, or processes (FEPs). Appendix SCR typically does not present great detail of those FEPs that are screened in to WIPP performance scenarios. The detail describing the implementation of screened in FEPs (such as N23, N24, N26, and N27) within a performance scenario is discussed as part of the CRA-2019 or reference is made to previous recertifications. Specifically, Appendix SCR states for N23, N24, N26, and N27 that groundwater flow is discussed in the Compliance Certification Application (CCA), Chapter 2.0, Section 2.2.1; and Chapter 6.0, Section 6.4.5 and Section 6.4.6. More recent discussions on groundwater investigations have historically been presented in Appendix HYDRO of each recertification. This avoids duplication of information, while reducing the likelihood of inconsistencies within the application. Conversely, for FEPs that are screened out of WIPP performance scenarios, a thorough screening argument is presented to sufficiently justify omitting the FEP from Performance Assessment (PA).

EPA Evaluation of Response to SCR-10b

The Agency understands that "great detail" need not be included in the screening argument for FEPs that are screened in because such detail can be incorporated by referring to those parts of the Department's CRAs where the detailed information is presented. EPA's comment requests only brief explanations in the screening argument and, most importantly, it requests references to detailed explanations in supporting documents. The only reference to supporting information provided in this screening argument is to the 1996 CCA, despite the fact that groundwater investigations have been ongoing at the WIPP for the past 25 years. DOE's response to this completeness comment refers us back in a circular fashion to the same section of the CRA, Appendix HYDRO, that we identified for the DOE in our comment. Because DOE is obviously aware that the more recent discussions on groundwater investigations have historically been presented in Appendix HYDRO, EPA would have expected that a reference to Appendix HYDRO would be included in the screening argument for these FEPs along with references to the CCA and other relevant sections of the CRAs.

DOE's screening discussion of groundwater characteristics and their response to this Completeness Comment provides a good example of EPA's more general concern that, when reading the screening arguments, it appears that *few Natural (N) FEPs appear to have received any updates.* EPA expects DOE to demonstrate a continuing awareness of new information on natural features, events, and processes relevant to WIPP performance and include them in the screening arguments either directly or by reference, whether or not they affect the screening decision.

SCR-10c. Changes in groundwater (N35, N36, N37), recharge and discharge (N53, N54, N55)

> *Similar to SCR-10b, new information from studies undertaken since the CCA should be noted and incorporated into the screening argument. For example, recent radiokrypton work by SNL and collaborators might help answer questions of the extent and timing of recharge into the Culebra. N53, N54, and N55 also deal with groundwater recharge. Paleoclimatology and climate modeling have advanced and evolved considerably over the past two decades. This section should identify and summarize new data that supports or refines the upper bound and lower bound estimates. This may be addressed in conjunction with the previously submitted comment CC3-HYDRO-1.*

DOE Response (from DOE Response Package 10 (DOE R10 2021))

The DOE employs a rigorous hydrologic monitoring program and an experimental program in the vicinity of the WIPP to verify that current models adequately represent the characteristics of the Culebra as they relate to predictions of performance. As stated in the response to CC3-HYDRO-1, monitoring data and experimental data continue to confirm that the current Culebra flow model is conservative with regard to anticipated travel times and radionuclide transport away from the repository.

With regard to FEPs N53, N54, and N55, the screening decision of "screened out due to low or no consequence," (SO-C) does not hinge on whether freshwater intrusion and changes in Eh and

pH occur, but rather whether these processes impact performance, if they were to occur. As stated in Appendix SCR-2019, Section SCR-4.3.1.3.3,

> "If recharge occurs mainly during periods of high precipitation (pluvials) associated with periods of continental glaciation, the consequences of such recharge are likely reflected in the ranges of geochemical conditions currently observed in the Culebra as a whole, as well as along the likely offsite transport pathway (the direction of flow from the point(s) at which brines from the repository would enter the Culebra in the event of human intrusion to the south or south-southeast and eventually to the boundary of the WIPP site). Hence, the effects of recharge, (possible) freshwater intrusion, and (possible) concomitant changes in groundwater Eh and pH can be screened out on the basis of low consequence to the performance of the far-field barrier. The reasons for the conclusion that the effects of pluvial recharge are inconsequential (i.e., are already included among existing variations in geochemical conditions) are (1) as many as 50 continental glaciations and associated pluvials have occurred since the late Pliocene Epoch 2.5 million yrs ago (2.5 million years before present [Ma BP]); (2) the glaciations and pluvials that have occurred since about 0.5 to 1 Ma BP have been significantly more severe than those that occurred prior to 1 Ma BP (see, for example, Servant 2001); and (3) conditions in the Culebra are favorable for retardation of actinides despite the effects of as many as 50 periods of recharge."

The DOE continues to believe that the current screening argument is adequate, and the validity of the screening decision is not in question.

EPA Evaluation of Response to SCR-10c

The DOE response was inadequate for both sets of FEPs addressed in this comment.

EPA believes that the DOE response beginning "With regard to FEPs N53, N54, and N55…" was actually intended to respond to the Agency's comment regarding FEPs N35, N36, and N37. These latter three FEPs are the ones that have been screened out due to low or no consequence while the former three FEPs have been screened in as UP (undisturbed performance). The Agency's evaluations of DOE's responses regarding each set of FEPs are presented below.

DOE screened out FEPs N35, N36, and N37 from WIPP PA on the basis of low consequence. DOE's response states, in summary, that if freshwater recharge to the Culebra occurs mainly during periods of high precipitation (pluvials) associated with periods of continental glaciation, the existing variations in groundwater E_h and pH in the Culebra are the consequences of those pluvials. DOE concludes that these variations are already included among the existing variations in geochemical conditions found in the Culebra and the effects of additional pluvial recharge are inconsequential in comparison. However, DOE's screening argument also identifies studies suggesting that exclusively modern recharge of significant quantities of recently introduced meteoric water may be occurring and reducing the salinity of Culebra groundwater, for example in Hydrochemical Zone B south of the WIPP site. It appears to the Agency that DOE's screening argument may actually not be independent of whether freshwater intrusion and changes in Eh and pH occur, which led to the observation in this completeness comment, that additional

information exists that might help answer questions of the extent and timing of recharge into the Culebra. In formulating this comment, EPA was not necessarily questioning the validity of the screening decision but was rather intending to provide another example of a screening argument where additional information has become available in the past 20 years and should be recognized even if the screening decision is not changed.

FEPs N53, N54, and N55 address groundwater recharge, discharge, and infiltration with regard to permeable horizons above the Salado. The amount of groundwater recharge reaching the Culebra is directly relevant to these FEPs. Again, the screening argument for these FEPs only references the 1996 CCA. Although EPA is aware that DOE employs rigorous Culebra monitoring and experimental programs, as stated in the DOE response to SCR-10c, no reference to these programs is provided in the screening argument for these FEPs. The Agency's Completeness Comment SCR-10c is not necessarily questioning the validity or conservative nature of the current Culebra flow model, but rather is providing an example of a screening argument that would significantly benefit from an update.

The Agency believes that DOE may have misunderstood the intent of CC5-SCR-10. This completeness comment was prepared to inform DOE of a lack of updates in some FEP screening arguments and the three parts of this comment were provided as examples. The comment was not presented so much as questioning screening decisions based on historic data but rather to request DOE to more comprehensively demonstrate a continuing awareness of current research related to natural and human-induced events and processes relevant to FEP screening. Changes in screening decisions that might arise because of the introduction of more recent information would only strengthen the Department's assessment of WIPP performance. The Agency expects that DOE will review and update the screening arguments for all natural and human-induced FEPs for the CRA-2024.

CC6-SCR-11: Updates to Seismic Activity FEP
40 CFR § 194.32 Scope of Performance Assessments

FEP documentation for SCR-4.1.3.2.4 Seismic Activity N12 (and related to previously submitted completeness question CC2-SCR-1) is missing significant, relevant updates from the published literature on seismic activity, especially induced seismicity in the Permian Basin Region, including the Delaware Basin.

> *EPA has identified several items in the published literature that should have been incorporated into the relevant discussions, including N12 and related FEPs such as N3 & N11 involving tectonics, faults and stress. Noting that significant research efforts continue by academic and industry consortia to investigate the patterns, causes, and hazards of induced seismicity in the Permian Basin region (e.g., TexNet & CISR at the Texas Bureau of Economic Geology, and ongoing research at New Mexico Tech/New Mexico Bureau of Geology & Mineral Resources), DOE will need to follow up on this for the next set of PA calculations submitted to EPA. Detailed study of regional seismicity, including induced seismicity, can trace subsurface fluid migration of hydrocarbons and*

wastewater, reveal and reactivate previously unknown faults, and delineate stress orientations, for example.

Appendix SCR notes an increase in regional seismicity and upgrades to the WIPP seismic network, but lacks detail and context. In fact, the Delaware Basin and surrounding region has in recent years had comparable amounts of seismicity to southern California. The FEP from CRA-2019 states

"Therefore, comparisons with previous data are difficult, and trending attempts are not yet meaningful. It is widely understood that these events are small in magnitude, and are obviously anthropogenic in nature, due to the increase in oil and gas exploration and production within the Basin. This new information does not change the screening argument or decision."

There has been a significant uptick in seismicity in the Permian Basin region, including the Delaware Basin over the past decade related to oil and gas activities, and requires a more comprehensive discussion than that found above. DOE is strongly advised to stay up to date with these developments and findings, plus solicit input and analysis from the New Mexico Tech Seismic Observatory (NMTSO) that operates the DOE-funded WIPP seismic network. Several new areas of elevated seismicity have been identified since the CCA, including Dagger Draw 30 miles WNW of WIPP (noted in CRA-2014), and the trans-Pecos region just over the border in Texas ~60 miles south of WIPP and within the Delaware Basin, yet these remain barely mentioned if at all in DOE's compliance documentation. The public concern for the latter area of the Delaware Basin is especially heightened following the M 5.0 earthquake that struck in March 2020.

Although minor seismicity is not expected to impact WIPP operations or long-term performance, this should be assessed using the most current information available. Several significant, relevant, recent publications that should be reviewed for future submissions include:

Ellsworth, W. L., 2013, Injection-induced earthquakes: *Science*, v. 341, no. 6142, p. 1225942.

Frohlich, C., DeShon, H., Stump, B., Hayward, C., Hornbach, M., and Walter, J. I., 2016, A Historical Review of Induced Earthquakes in Texas: *Seismological Research Letters*, v. 87, no. 4, p. 1022-1038.

Lund Snee, J.-E. and M. D. Zoback (2016). "State of stress in Texas: Implications for induced seismicity." *Geophysical Research Letters* 43(19): 10,208-210,214.

Zhang, Y., Edel, S. S., Pepin, J., Person, M., Broadhead, R., Ortiz, J. P., Bilek, S. L., Mozley, P., and Evans, J. P., 2016, Exploring the potential linkages between oil-field brine reinjection, crystalline basement permeability, and triggered seismicity for the Dagger Draw Oil field, southeastern New Mexico, USA, using hydrologic modeling: *Geofluids*, v. 16, no. 5, p. 971-987.

The discussion on groundshaking (SCR-4.1.3.2.4.5) relies on dated studies, and no explicit mention is made regarding the Design Basis Earthquake (DBE) for surface facilities. The actual DBE value of 0.1 g was only identified as such and found in RCRA documentation, not in the Compliance Recertification Application. True, the risk to underground excavations from groundshaking is very low and they are unlikely to be impacted, especially at repository depth. However, DOE's references are dated, and newer references should be evaluated and incorporated into future discussions in the screening decisions, for example:

Jaramillo, C. A. (2017). Impact of seismic design on tunnels in rock – Case histories. *Underground Space*, 2(2), 106-114. doi:10.1016/j.undsp.2017.03.004

Oliaei, M., & Basirat, R. (2019). The Effect of Earthquake Frequency Content on the Internal Forces in the Tunnels Permanent Lining. *Journal of Earthquake Engineering*, 1-20. doi:10.1080/13632469.2019.1693445

Tsinidis, G., de Silva, F., Anastasopoulos, I., Bilotta, E., Bobet, A., Hashash, Y. M. A., Fuentes, R. (2020). Seismic behaviour of tunnels: From experiments to analysis. *Tunneling and Underground Space Technology*, 99. doi:10.1016/j.tust.2020.103334

DOE Response (from DOE Response Package 10 (DOE R10 2021))

The DOE's response to completeness question CC3-SCR-5b describes the design basis earthquake (DBE) for the WIPP and notes that a Richter magnitude 5.5 earthquake at the site, a 6.0 magnitude earthquake on the Central Basin Platform, and a 7.8 magnitude earthquake in the Basin and Range sub-region were considered (see the Compliance Certification Application (CCA) Chapter 2.6 (DOE 1996) for a discussion of seismology of the WIPP site, and Chapter 2.6.2.4 for a discussion of the DBE). References cited in the response to CC3-SCR-5b (Pratt et al. 1979, and Sharma and Judd 1991) conclude that mine experience and studies on earthquake damage to underground workings show that tunnels are not damaged at sites having peak surface accelerations less than 0.2 g. Using the design basis magnitudes mentioned above (5.5, 6.0, and 7.8), peak surface accelerations are estimated to be 0.075 g at the WIPP. The conservative 1,000-year estimates are still well below the magnitude known to initiate sub-surface damage.

The EPA's comment states that information regarding the DBE is lacking from Appendix SCR-2019 and the Compliance Recertification Application-2019, although it is present in the RCRA documentation. Because this information was presented in the CCA, Chapter 2.6 (DOE 1996), the DOE considers this information to be part of the current compliance basis. The DOE does not discuss the effects of the DBE on surface facilities since they do not have a role in long-term isolation and performance of the repository; operational aspects of WIPP are not relevant to demonstrations of compliance with 40 CFR Part 191.

The DOE notes that two of the studies mentioned above by the EPA were released after the data cut-off for the CRA-2019 and not available for consideration. Nonetheless, these and newer studies will be considered in the next update to Appendix SCR.

DOE Reference

U.S. Department of Energy (DOE). 1996. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant. October 1996. Carlsbad Field Office, Carlsbad, NM. DOE/CAO-1996-2184.

EPA Evaluation of Response

The DOE response was adequate. The screening argument for seismic activity is illustrative of the Agency's concern regarding a lack of updated technical information. Although DOE acknowledges the increased capability to detect very small seismic events since 2016, the screening argument discussion of the causes of seismic activity cites sources from the 1970s and 1980s, and the discussion of seismic risk in the region of the WIPP cites only the 1996 CCA. DOE has committed to consider newer studies in the next update to Appendix SCR.

Source Citations for DOE Completeness Question Response Packages

DOE RP6 (U.S. Department of Energy) 2020. Response 6 to U.S. Environmental Protection Agency's 2019 Compliance Recertification Application Completeness Comments Letters dated March 23, 2020, May 6, 2020, and July 17, 2020 from Tom Peake to Mike Brown. Letter from Reinhard Knerr (DOE) to Lee Veal (EPA). CBFO:OEP:MRB:MC:20-0277:UFC 5486.00. U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico. October 26, 2020. (Sixth Response Package).

DOE RP7 (U.S. Department of Energy) 2020. Response 7 to U.S. Environmental Protection Agency's 2019 Compliance Recertification Application Completeness Comments Letters dated May 6, 2020, June 12, 2020, July 17, 2020 and September 11, 2020 from Tom Peake to Mike Brown. Letter from Reinhard Knerr (DOE) to Lee Veal (EPA). CBFO:OEP:MRB:MC:20-1508:UFC 5486.00. U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico. December 1, 2020. (Seventh Response Package).

DOE RP9 (U.S. Department of Energy) 2021. Response 9 to U.S. Environmental Protection Agency's 2019 Compliance Recertification Application Completeness Comments Letters dated September 11, 2020 and November 13, 2020, from Tom Peake to Mike Brown. Letter from Reinhard Knerr (DOE) to Lee Veal (EPA). CBFO:OEP:MRB:MC:21-0207:UFC 5486.00. Carlsbad, New Mexico. March 4, 2021. (Ninth Response Package).

DOE RP10 (U.S. Department of Energy) 2021. Response 10 to U.S. Environmental Protection Agency's 2019 Compliance Recertification Application Completeness Comments, Letters dated September 11, 2020 and November 13, 2020, from Tom Peake to Mike Brown. Letter from Reinhard Knerr (DOE) to Lee Veal (EPA). CBFO:OEP:MRB:MC:21-0211:UFC 5486.00 Carlsbad, New Mexico. March 30, 2021. (Tenth Response Package).