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Compliance Recertification Application 2014
for the
Waste Isolation Pilot Plant

Appendix SCR-2014
Feature, Event, and Process Screening for PA

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Field Office
Carlsbad, New Mexico

Compliance Recertification Application 2014
Appendix SCR-2014
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Acronyms and Abbreviations

µm	micrometer
AIC	active institutional controls
Bq	becquerels
°C	degrees centigrade
CAG	Compliance Application Guidance
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CDF	cumulative distribution function
CFR	Code of Federal Regulations
CH-TRU	contact-handled transuranic
Ci	curie
cm	centimeter
CRA	Compliance Recertification Application
DBDSP	Delaware Basin Drilling Surveillance Program
DFR	driving force ratio
DOE	U.S. Department of Energy
DP	disturbed performance
DRZ	disturbed rock zone
EP	event and process
EPA	U.S. Environmental Protection Agency
ERMS	Electronic Record Management System
°F	degrees Fahrenheit
FEP	feature, event, and process
FLAC	Fast Lagrangian Analysis Continua
FSU	Florida State University
ft	foot/feet
ft^2	square foot
ft^3	cubic foot
g	gram
gal	gallon
gpm	gallons per minute

H	human-initiated
HCN	historic, current, and near-future
hr	hour
IB	inside boundary
in.	inch/inches
K_d	retardation distribution coefficient
kg	kilogram
kg/m^3	kilograms per cubic meter
km	kilometer
km^2	square kilometer
kW	kilowatt
L	liter
lb/gal	pounds per gallon
LWA	Land Withdrawal Act
m	meter
m^2	square meter
m^3	cubic meter
Ma BP	million years before present
MB	marker bed
MeV	megaelectron volt
mi	mile
mL	milliliter
MPa	megapascal
MPI	Mississippi Potash Inc.
mV	millivolt
N	natural
OB	outside boundary
oz	ounce
PA	performance assessment
PABC	Performance Assessment Baseline Calculation
PAVT	Performance Assessment Verification Test
PCN	planned change notice
PIC	passive institutional control

ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
RH-TRU	remote-handled transuranic
s	second
SDDI	Salt Defense Disposal Investigations
SDI	Salt Disposal Investigations
SKI	Statens Kärnkraftinspektion
SO-C	screened-out consequence
SO-P	screened-out probability
SO-R	screened-out regulatory
T-field	transmissivity field
TRU	transuranic
UP	undisturbed performance
V	volt
W	waste and repository-induced
W	watt
W/Ci	watts per curie
W/g	watts per gram
WIPP	Waste Isolation Pilot Plant
yd^3	cubic yard
yr	year
yrs	years

Elements and Chemical Compounds

Al	aluminum
Am	americium
An	actinide
CH_4	methane
CO_2	carbon dioxide
Cs	cesium
EDTA	ethylenediaminetetraacetate
Fe	iron

MgO	magnesium oxide
Np	neptunium
Pm	promethium
Pu	plutonium
Rn	radon
Sr	strontium
Th	thorium
U	uranium

SCR-1.0 Introduction

The U.S. Department of Energy (DOE) has developed the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico for the disposal of transuranic (TRU) wastes generated by defense programs. In May of 1998, the U.S. Environmental Protection Agency (EPA) certified that the WIPP would meet the disposal standards (U.S. EPA 1998a, p. 27405) established in 40 CFR Part 191 Subparts B and C (U.S. EPA 1993), thereby allowing the WIPP to begin waste disposal operations. This certification was based, in part, on performance assessment (PA) calculations that were included in the DOE's Compliance Certification Application (CCA) (U.S. DOE 1996). These calculations demonstrate that the cumulative releases of radionuclides to the accessible environment will not exceed those allowed by the EPA standard.

The WIPP Land Withdrawal Act (LWA) (U.S. Congress 1992) requires the WIPP to be recertified (demonstrating continued compliance with the disposal standards) every five years (yrs). As such, the DOE prepared the 2004 Compliance Recertification Application (CRA-2004) (U.S. DOE 2004), which demonstrated that the WIPP complied with the EPA's requirements for radioactive waste disposal. The CRA-2004 included changes to the WIPP long-term compliance baseline since the CCA. As a result of the CRA-2004 and information provided in response to specific requests, the EPA recertified the WIPP on March 29, 2006 (U.S. EPA 2006). Subsequently, this recertification process was repeated by the DOE with its submittal of the CRA-2009 (U.S. DOE 2009). Again, the EPA carefully reviewed the application, and after requesting additional information and calculations, recertified that the WIPP continued to comply with the long-term disposal requirements of 40 CFR Part 191 and the compliance criteria of 40 CFR Part 194 (U.S. EPA 1996a) in November 2010 (U.S. EPA 2010a). Currently, and in compliance with the requirements for periodic recertification, the DOE has prepared the CRA-2014, which documents changes since the CRA-2009, and demonstrates compliance with the long-term disposal requirements of 40 CFR Part 191 and the compliance criteria of 40 CFR Part 194.

To assure that PA calculations account for important aspects of the disposal system, features, events, and processes (FEPs) considered to be potentially important to the disposal system are identified. These FEPs are used as a tool for determining what phenomena and components of the disposal system are dealt with in PA calculations. For the WIPP CCA, a systematic process was used to compile, analyze, screen, and document FEPs for use in PA. The FEP screening process used in the CCA, the CRA-2004, the CRA-2009, and this CRA-2014 is described in detail in the CCA, Chapter 6.0, Section 6.2. For recertification applications, this process evaluates any new information that may have impacts on or present inconsistencies to those screening arguments and decisions presented since the last certification or recertification. The FEPs baseline is managed according to Sandia Activity/Project Specific Procedure 9-4, *Performing FEPs Baseline Impact Assessment for Planned or Unplanned Changes* (Revision 3) (Kirkes 2013a). For the CRA-2014, a reassessment of FEPs concluded that of the 245 FEPs considered for the CRA-2009, 184 have not been changed and 61 have been updated with new information. Of the 61 updated FEPs, one has also had its screening decision changed. Therefore, there are 245 WIPP FEPs for the CRA-2014.

SCR-2.0 Basis for FEPs Screening Process

SCR-2.1 Requirement for FEPs

The origin of FEPs is related to the EPA's radioactive waste disposal standard's requirement to use PA methodology. The DOE was required to demonstrate that the WIPP complied with the containment requirements of section 191.13 (U.S. EPA 1993). These requirements state that the DOE must use PA to demonstrate that radionuclide releases from the disposal system during the 10,000 yrs following closure will fall below specified limits. The PA analyses supporting this determination must be quantitative and must consider uncertainties caused by all significant processes and events that may affect the disposal system, including inadvertent human intrusion into the repository during the future. The scope of PA is further defined by the EPA at section 194.32 (U.S. EPA 1996a), which states,

> Any compliance application(s) shall include information which:
>
> (1) Identifies all potential processes, events or sequences and combinations of processes and events that may occur during the regulatory time frame and may affect the disposal system;
>
> (2) Identifies the processes, events or sequences and combinations of processes and events included in performance assessments; and
>
> (3) Documents why any processes, events or sequences and combinations of processes and events identified pursuant to paragraph (e)(1) of this section were not included in performance assessment results provided in any compliance application.

Therefore, the PA methodology includes a process that compiles a comprehensive list of the FEPs that are potentially relevant to disposal system performance. Those FEPs shown by screening analysis to have the potential to affect performance are represented in scenarios and quantitative calculations using a system of linked computer models to describe the interaction of the repository with the natural system, both with and without human intrusion. For the CCA, the DOE first compiled a comprehensive list of FEPs, which was then subjected to a screening process that eventually lead to the set of FEPs used in PA to demonstrate the WIPP's compliance with the long-term disposal standards.

SCR-2.2 FEPs List Development for the CCA

As a starting point, the DOE assembled a list of potentially relevant FEPs from the compilation developed by Stenhouse, Chapman, and Sumerling (Stenhouse, Chapman, and Sumerling 1993) for the Swedish Nuclear Power Inspectorate (Statens Kärnkraftinspektion, or SKI). The SKI list was based on a series of FEP lists developed for other disposal programs and is considered the best-documented and most comprehensive starting point for the WIPP. For the SKI study, an initial raw FEP list was compiled based on nine different FEP identification studies.

The compilers of the SKI list eliminated a number of FEPs as irrelevant to the particular disposal concept under consideration in Sweden. These FEPs were reinstated for the WIPP effort, and several FEPs on the SKI list were subdivided to facilitate screening for the WIPP. Finally, to ensure comprehensiveness, other FEPs specific to the WIPP were added based on review of key project documents and broad examination of the preliminary WIPP list by both project participants and stakeholders. The initial unedited list is contained in the CCA, Appendix SCR, Attachment 1. The initial unedited FEP list was restructured and revised to derive the comprehensive WIPP FEP list used in the CCA. The number of FEPs was reduced to 237 in the CCA to eliminate the ambiguities and duplications presented in a generic list. Restructuring the list did not remove any substantive issues from the discussion. As discussed in more detail in the CCA, Appendix SCR, Attachment 1, the following steps were used to reduce the initial unedited list to the appropriate WIPP FEP list used in the CCA.

- References to subsystems were eliminated because the SKI subsystem classification was not appropriate for the WIPP disposal concept. For example, in contrast to the Swedish disposal concept, canister integrity does not have a role in post-operational performance of the WIPP, and the terms near-field, far-field, and biosphere were not unequivocally defined for the WIPP site.

- Duplicate FEPs were eliminated. Duplicate FEPs arose in the SKI list because individual FEPs could act in different subsystems. FEPs had a single entry in the CCA list whether they were applicable to several parts of the disposal system or to a single part only (for example, the FEP Gas Effects). Disruption appears in the seals, backfill, waste, canister, and near-field subsystems in the initial FEP list. These FEPs were represented by a single FEP, Disruption Due to Gas Effects.

- FEPs that were not relevant to the WIPP design or inventory were eliminated. Examples include FEPs related to high-level waste, copper canisters, and bentonite backfill.

- FEPs relating to engineering design changes were eliminated because they were not relevant to a compliance application based on the DOE's design for the WIPP.

- FEPs relating to constructional, operational, and decommissioning errors were eliminated. The DOE has administrative and quality control procedures to ensure that the facility will be constructed, operated, and decommissioned properly.

- Detailed FEPs relating to processes in the surface environment were aggregated into a small number of generalized FEPs. For example, the SKI list includes the biosphere FEPs Inhalation of Salt Particles, Smoking, Showers and Humidifiers, Inhalation and Biotic Material, Household Dust and Fumes, Deposition (Wet and Dry), Inhalation and Soils and Sediments, Inhalation and Gases and Vapors (Indoor and Outdoor), and Suspension in Air, which were represented by the FEP Inhalation.

- FEPs relating to the containment of hazardous metals, volatile organic compounds, and other chemicals not regulated by Part 191 were not included.

- A few FEPs were renamed to be consistent with terms used to describe specific WIPP processes (for example, Wicking, Brine Inflow).

These steps resulted in a list of WIPP-relevant FEPs retained for further consideration in the first certification PA. These FEPs were screened to determine which would be included in the PA models and scenarios for the CCA PA. As mentioned in Section SCR-1.0, the FEPs baseline is managed by procedure to be systematically reviewed and updated prior to each recertification application. As a result of this process, the CRA-2004 included 235 WIPP FEPs, and both the CRA-2009 and CRA-2014 include 245 WIPP FEPs. These evaluations are documented in Wagner et al. (Wagner et al. 2003), Kirkes (Kirkes 2008), and Kirkes (Kirkes 2013b), respectively.

SCR-2.3 Criteria for Screening of FEPs and Categorization of Retained FEPs

The purpose of FEP screening is to identify those FEPs that should be accounted for in PA calculations, and those FEPs that need not be considered further. The DOE's process of removing FEPs from consideration in PA calculations involved the structured application of explicit screening criteria. The criteria used to screen out FEPs are explicit regulatory exclusion (SO-R), probability (SO-P), or consequence (SO-C). All three criteria are derived from regulatory requirements. FEPs not screened out as SO-R, SO-P, or SO-C were retained for inclusion in PA calculations and are classified as either undisturbed performance (UP) or disturbed performance (DP) FEPs.

SCR-2.3.1 Regulation (SO-R)

Specific FEP screening criteria are stated in Part 191 and Part 194. Such screening criteria relating to the applicability of particular FEPs represent screening decisions made by the EPA. That is, in the process of developing and demonstrating the feasibility of the Part 191 standard and the Part 194 criteria, the EPA considered and made conclusions on the relevance, consequence, and probability of particular FEPs occurring. In so doing, it allowed some FEPs to be eliminated from consideration.

SCR-2.3.2 Probability of Occurrence of a FEP Leading to Significant Release of Radionuclides (SO-P)

Low-probability events can be excluded on the basis of the criterion provided in section 194.32(d), which states, "performance assessments need not consider processes and events that have less than one chance in 10,000 of occurring over 10,000 years." In practice, for most FEPs screened out on the basis of low probability of occurrence, it has not been possible to estimate a meaningful quantitative probability. In the absence of quantitative probability estimates, a qualitative argument was used.

SCR-2.3.3 Potential Consequences Associated with the Occurrence of the FEPs (SO-C)

The DOE recognizes two uses for this criterion:

1. FEPs can be eliminated from PA calculations on the basis of insignificant consequence. Consequence can refer to effects on the repository or site or to radiological consequence. In particular, section 194.34(a) (U.S. EPA 1996a) states, "The results of performance

assessments shall be assembled into 'complementary, cumulative distribution functions' (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events." The DOE has omitted events and processes (EPs) from PA calculations where there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

2. FEPs that are potentially beneficial to subsystem performance may be eliminated from PA calculations if necessary to simplify the analysis. This argument may be used when there is uncertainty as to exactly how the FEP should be incorporated into assessment calculations or when incorporation would incur unreasonable difficulties.

In some cases, the effects of the particular event or process occurring, although not necessarily insignificant, can be shown to lie within the range of uncertainty of another FEP already accounted for in the PA calculations. In such cases, the event or process may be included in PA calculations implicitly, within the range of uncertainty associated with the included FEP.

Although some FEPs could be eliminated from PA calculations on the basis of more than one criterion, the most practical screening criterion was used for classification. In particular, a regulatory screening classification was used in preference to a probability or consequence screening classification. FEPs that have not been screened out based on any of the three criteria were included in the PA.

SCR-2.3.4 UP FEPs

FEPs classified as UP are accounted for in calculations of UP of the disposal system. UP is defined in section 191.12 (U.S. EPA 1993) as "the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." The UP FEPs are accounted for in the PA calculations to evaluate compliance with the containment requirements in section 191.13. Undisturbed PA calculations are also used to demonstrate compliance with the individual and groundwater protection requirements of section 191.15 (U.S. EPA 1993) and Part 191 Subpart C, respectively.

SCR-2.3.5 DP FEPs

The FEPs classified as DP are accounted for only in assessment calculations for DP. The DP FEPs that remain following the screening process relate to the potential disruptive effects of future drilling and mining events in the controlled area. Consideration of both DP and UP FEPs is required to evaluate compliance with section 191.13.

SCR-2.4 FEPs Categories and Timeframes

In the following sections, FEPs are discussed under the categories Natural FEPs, Human-Induced EPs, and Waste- and Repository-Induced FEPs. Identifiers (IDs) of Natural FEPs begin with "N," IDs of Human-Induced EPs begin with "H," and IDs of Waste- and Repository-Induced FEPs begin with "W." The FEPs are also considered within time frames during which they may occur. Because of the regulatory requirements concerning human activities, two time periods were used when evaluating human-induced EPs. These time frames were defined as Historical, Current, and Near-Future Human Activities (HCN) and Future Human Activities (Future). These time frames are also discussed in Section SCR-2.4.2.

SCR-2.4.1 Description of Natural FEPs

Natural FEPs are those that relate to hydrologic, geologic, and climate conditions that have the potential to affect long-term performance of the WIPP disposal system over the regulatory time frame. These FEPs do not include the impacts of other human-related activities such as the effect of boreholes on FEPs related to natural changes in groundwater chemistry. Only natural FEPs are included in the screening process.

Consistent with section 194.32(d), the DOE has screened out several natural FEPs from PA calculations on the basis of a low probability of occurrence at or near the WIPP site. In particular, natural events for which there is no evidence indicating that they have occurred within the Delaware Basin have been screened on this basis. For FEPs analysis, the probabilities of occurrence of these events are assumed to be zero. Quantitative, nonzero probabilities for such events, based on numbers of occurrences, cannot be ascribed without considering regions much larger than the Delaware Basin, thus neglecting established geological understanding of the FEPs that occur within particular geographical provinces.

In considering the overall geological setting of the Delaware Basin, the DOE has eliminated many FEPs from PA calculations on the basis of low consequence. FEPs that have had little effect on the characteristics of the region in the past are expected to be of low consequence for the regulatory time period.

SCR-2.4.2 Description of Human-Induced EPs

Human-induced EPs (Human EPs) are those associated with human activities in the past, present, and future. The EPA provided guidance in their regulations concerning which human activities are to be considered, their severity, and the manner in which to include them in the future predictions.

The scope of PAs is clarified with respect to human-induced EPs in section 194.32. At section 194.32(a), the EPA states,

> Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame.

Thus, PAs must include consideration of human-induced EPs relating to mining and drilling activities that might take place during the regulatory time frame. In particular, PAs must consider the potential effects of such activities that might take place within the controlled area at a time when institutional controls cannot be assumed to completely eliminate the possibility of human intrusion.

Further criteria concerning the scope of PAs are provided at section 194.32(c):

> Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

In order to implement the criteria in section 194.32 relating to the scope of PAs, the DOE has divided human activities into three categories: (1) human activities currently taking place and those that took place prior to the time of the compliance application, (2) human activities that might be initiated in the near future after submission of the compliance application, and (3) human activities that might be initiated after repository closure. The first two categories of EPs, corresponding to the HCN time frame, are considered under UP, and EPs in the third category, which belong to the Future time frame, may lead to DP conditions. A description of these three categories follows.

1. Historical and current human activities include resource-extraction activities that have historically taken place and are currently taking place outside the controlled area. These activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. Current human activities taking place within the controlled area are essentially those associated with development of the WIPP repository. Historic human activities include existing boreholes.

2. Near-future human activities include resource-extraction activities that may be expected to occur outside the controlled area based on existing plans and leases. Thus, the near future includes the expected lives of existing mines and oil and gas fields, and the expected lives of new mines and oil and gas fields that the DOE expects will be developed based on existing plans and leases. These activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. The only human activities expected to occur within the controlled area in the near future are those associated with development of the WIPP repository. The DOE expects that any activity initiated in the near future, based on existing plans and leases, will be initiated prior to repository closure. Activities initiated prior to repository closure are assumed to continue until their completion.

3. Future human activities include activities that might be initiated within or outside the controlled area after repository closure. This includes drilling and mining for resources within the disposal system at a time when institutional controls cannot be assumed to completely eliminate the possibility of such activities. Future human activities could influence the transport of contaminants within and outside the disposal system by directly removing waste from the disposal system or altering the geological, hydrological, or geochemical characteristics of the disposal system.

SCR-2.4.2.1 Scope of Future Human Activities in PA

PAs must consider the effects of future human activities on the performance of the disposal system. The EPA has provided criteria relating to future human activities in section 194.32(a), which limits the scope of consideration of future human activities in PAs to mining and drilling.

SCR-2.4.2.1.1 Criteria Concerning Future Mining

The EPA provides the following additional criteria concerning the type of future mining that should be considered by the DOE in section 194.32(b):

> Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur. Complete removal of such mineral resources shall be assumed to occur only once during the regulatory time frame.

Thus, consideration of future mining may be limited to mining within the controlled area at the locations of resources that are similar in quality and type to those currently extracted from the Delaware Basin. Potash is the only resource that has been identified within the controlled area in quality similar to that currently mined from underground deposits elsewhere in the Delaware Basin. The hydrogeological impacts of future potash mining within the controlled area are accounted for in calculations of the DP of the disposal system. Consistent with section 194.32(b), all economically recoverable resources in the vicinity of the disposal system (outside the controlled area) are assumed to be extracted in the near future.

SCR-2.4.2.1.2 Criteria Concerning Future Drilling

With respect to consideration of future drilling, in the preamble to Part 194, the EPA

> …reasoned that while the resources drilled for today may not be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled.

Criteria concerning the consideration of future deep and shallow drilling in PAs are provided in section 194.33 (U.S. EPA 1996a). The EPA also provides a criterion in section 194.33(d) concerning the use of future boreholes subsequent to drilling:

> With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

Thus, PAs need not consider the effects of techniques used for resource extraction and recovery that would occur subsequent to the drilling of a borehole in the future. These activities are screened SO-R.

The EPA provides an additional criterion that limits the severity of human intrusion scenarios that must be considered in PAs. In section 194.33(b)(1) the EPA states,

> Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario.

SCR-2.4.2.1.3 Screening of Future Human EPs

Future Human EPs accounted for in PA calculations for the WIPP are those associated with mining and deep drilling within the controlled area at a time when institutional controls cannot be assumed to completely eliminate the possibility of such activities. All other future Human EPs, if not eliminated from PA calculations based on regulation, have been eliminated based on low consequence or low probability. For example, the effects of future shallow drilling within the controlled area were eliminated from CCA PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-2.4.3 Description of Waste- and Repository-Induced FEPs

The waste- and repository-induced FEPs are those that relate specifically to the waste material, waste containers, shaft seals, magnesium oxide (MgO) backfill, panel closure system (PCS), repository structures, and investigation boreholes. All FEPs related to radionuclide chemistry and radionuclide migration are included in this category. The FEPs related to radionuclide transport resulting from future borehole intersections of the WIPP excavation are defined as waste- and repository-induced FEPs.

SCR-3.0 FEPs

The reassessment of FEPs (Kirkes 2013b) results in a new FEPs baseline for CRA-2014. As discussed in Section SCR-1.0, 184 of the 245 WIPP FEPs have not changed since the CRA-2009. However, 61 FEPs required updates to their FEP descriptions and/or screening arguments, one of which has also had its screening decision changed. The single screening decision change does not result in a new FEP incorporated into PA calculations; the particular FEP will now be screened out of PA. Thus, the CRA-2014 considers 245 WIPP FEPs.

Table SCR-1 outlines the results of the assessment, and subsequent sections of this document present the actual screening decisions and supporting arguments. Those FEPs not separated by gridlines in the first column of Table SCR-1 have been addressed by group because of close similarity with other FEPs within that group. This grouping process was formerly used in the CCA and also by the EPA in its Technical Support Document for section 194.32 (U.S. EPA 1998b).

Table SCR-1. FEPs Summary for CRA-2014

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 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

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
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
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	No	SO-C
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

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
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
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	No change	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)

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
H9	Enhanced Oil and Gas Recovery	No change	No	SO-C (HCN) DP (Future)
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	No change	No	SO-C (HCN) DP (Future)
H22	Drilling Fluid Loss	No change	No	SO-C (HCN) DP (Future)

Table SCR-1. FEPs Summary for CRA-2014

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	No change	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 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)
H36	Borehole-Induced Geochemical Changes	No change	No	UP (HCN) DP (Future) SO-C (for units other than the Culebra)

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
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)
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)

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
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	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	Updated with new information regarding additional mined area used for experiments	No	UP
W2	Waste Inventory	Updated to reflect the inventory data sources used for the CRA-2014 PA	No	UP
W3	Heterogeneity of Waste Forms	Updated to reflect the inventory data sources used for the CRA-2014 PA	No	DP
W4	Container Form	Updated to reflect the inventory data sources used for the CRA-2014 PA	No	SO-C – Beneficial
W5	Container Material Inventory	Updated to reflect the inventory data sources used for the CRA-2014 PA	No	UP
W6	Shaft Seal Geometry	No change	No	UP
W7	Shaft Seal Physical Properties	No change	No	UP

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W109	Panel Closure Geometry	Updated with new information on panel closure design	No	UP
W110	Panel Closure Physical Properties	Updated with new information on panel closure design	No	UP
W8	Shaft Seal Chemical Composition	No change	No	SO-C Beneficial
W111	Panel Closure Chemical Composition	Updated with new information on panel closure design	No	SO-C Beneficial
W9	Backfill Physical Properties	No change	No	SO–C
W10	Backfill Chemical Composition	Updated to reflect implementation of water balance in PA	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-2014 PA	No	SO-C
W14	Nuclear Criticality: Heat	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-P
W15	Radiological Effects on Waste	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-C
W16	Radiological Effects on Containers	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-C

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W17	Radiological Effects on Shaft Seals	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-C
W112	Radionuclide Effects on Panel Closures	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-C
W18	Disturbed Rock Zone (DRZ)	Updated to include new panel closure implementation	No	UP
W19	Excavation-Induced Changes in Stress	Updated to include new panel closure implementation	No	UP
W20	Salt Creep	Updated to include new panel closure implementation	No	UP
W21	Changes in the Stress Field	Updated to include new panel closure implementation	No	UP
W22	Roof Falls	No change	No	UP
W23	Subsidence	No change	No	SO-C
W24	Large Scale Rock Fracturing	No change	No	SO-P
W25	Disruption Due to Gas Effects	No change	No	UP
W26	Pressurization	Updated to reference new corrosion experiments and associated parameters	No	UP
W27	Gas Explosions	No change	No	UP
W28	Nuclear Explosions	Updated to reflect the inventory used for the CRA-2014 PA	No	SO-P

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W29	Thermal Effects on Material Properties	Updated to reflect the inventory used for the CRA-2014 and planned thermal experiments	No	SO-C
W30	Thermally-Induced Stress Changes	Updated to reflect the inventory used for the CRA-2014 and planned thermal experiments	No	SO-C
W31	Differing Thermal Expansion of Repository Components	Updated to reflect the inventory used for the CRA-2014 and planned thermal experiments	No	SO-C
W72	Exothermic Reactions	Updated to reflect the inventory used for the CRA-2014 and planned thermal experiments	No	SO-C
W73	Concrete Hydration	Updated to reflect the inventory used for the CRA-2014 and planned thermal experiments	No	SO-C
W32	Consolidation of Waste	No change	No	UP
W36	Consolidation of Shaft Seals	No change	No	UP
W37	Mechanical Degradation of Shaft Seals	No change	No	UP
W39	Underground Boreholes	No change	No	UP

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W113	Consolidation of Panel Closures	Updated screening argument with new information regarding panel closure composition	No	UP
W114	Mechanical Degradation of Panel Closures	Updated screening argument with new information regarding panel closure composition	No	UP
W33	Movement of Containers	Updated to reference new inventory data	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 water balance implementation in PA	No	UP
W41	Wicking	Updated to reflect water balance implementation in PA	No	UP
W42	Fluid Flow Due to Gas Production	Updated to reflect water balance implementation in PA and new steel corrosion rates	No	UP
W43	Convection	Updated to reflect planned thermal experiments	No	SO-C
W44	Degradation of Organic Material	Updated to reference new inventory data	No	UP

Table SCR-1. FEPs Summary for CRA-2014

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 data	No	UP
W48	Effects of Biofilms on Microbial Gas Generation	Updated to reference new inventory data	No	UP
W46	Effects of Pressure on Microbial Gas Generation	No change	No	SO-C
W47	Effects of Radiation on Microbial Gas Generation	Updated with new radionuclide inventory and information related to the EPA request for additional information on CRA-2009	No	SO-C
W49	Gases from Metal Corrosion	Updated to reference new corrosion experiments and inventory	No	UP
W51	Chemical Effects of Corrosion	Updated to reference new corrosion experiments and inventory	No	UP
W50	Galvanic Coupling (Within the Repository)	No change	No	SO-C
W52	Radiolysis of Brine	No change	No	SO-C
W53	Radiolysis of Cellulose	Screening argument updated with new radionuclide inventory	No	SO-C
W54	Helium Gas Production	Screening argument updated with new radionuclide inventory	No	SO-C
W55	Radioactive Gases	Updated to reference new inventory data	No	SO-C

Table SCR-1. FEPs Summary for CRA-2014

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	No change	No	SO-C
W68	Organic Complexation	Updated to reflect implementation of variable brine volume in PA	No	UP
W69	Organic Ligands	Updated to reflect implementation of variable brine volume, new inventory data	No	UP

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W71	Kinetics of Organic Complexation	No change	No	SO-C
W70	Humic and Fulvic Acids	No change	No	UP
W74	Chemical Degradation of Shaft Seals	No change	No	UP
W76	Microbial Growth on Concrete	No change	No	UP
W115	Chemical Degradation of Panel Closures	Updated screening argument with new panel closure materials	Yes	SO-P
W75	Chemical Degradation of Backfill	No change	No	SO-C
W77	Solute Transport	No change	No	UP
W78	Colloid Transport	No change	No	UP
W79	Colloid Formation and Stability	No change	No	UP
W80	Colloid Filtration	No change	No	UP
W81	Colloid Sorption	No change	No	UP
W82	Suspensions of Particles	No change	No	DP
W83	Rinse	No change	No	SO-C
W84	Cuttings	No change	No	DP
W85	Cavings	Updated with new waste shear strength data	No	DP
W86	Spallings	Updated with new water balance implementation	No	DP
W87	Microbial Transport	No change	No	UP
W88	Biofilms	No change	No	SO-C Beneficial
W89	Transport of Radioactive Gases	Updated to reference CRA-2014 inventory data	No	SO-C
W90	Advection	No change	No	UP
W91	Diffusion	No change	No	UP
W92	Matrix Diffusion	No change	No	UP

Table SCR-1. FEPs Summary for CRA-2014

EPA FEP I.D.[a,b,c, d]	FEP Name	Screening Argument Update?	Screening Decision Changed?	Screening Classification
W93	Soret Effect	Updated based on new inventory data	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	No change	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)
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.

1

SCR-4.0 Screening of Natural FEPs

This section presents the screening arguments and decisions for natural FEPs. Natural FEPs may be important to the performance of the disposal system. Screening of natural FEPs is done in the absence of human influences on the FEPs. Of the 70 natural FEPs, 68 remain completely unchanged and two have been updated to include additional information. No screening decisions (classifications) for natural FEPs were changed, and no additional natural FEPs have been identified.

SCR-4.1 Geological FEPs

SCR-4.1.1 Stratigraphy

SCR-4.1.1.1 **FEP Numbers:** N1 and N2
FEP Titles: *Stratigraphy* (N1)
Brine Reservoir (N2)

SCR-4.1.1.2 Screening Decision: UP (N1)
DP (N2)

The *Stratigraphy* of the geological formations in the region of the WIPP is accounted for in PA calculations. The presence of *Brine Reservoirs* in the Castile Formation (hereafter referred to as the Castile) is accounted for in PA calculations.

SCR-4.1.1.2.1 Summary of New Information

Since the CRA-2009, new information has been gathered and analyzed that supports changing the probability that pressurized brine will be intercepted in WIPP intrusion scenarios. Kirchner et al. (Kirchner et al. 2012) describes the methodology and rationale for arriving at the updated parameter distribution for the PA parameter GLOBAL:PBRINE. This updated parameter does not change the screening argument or decision from the CRA-2009; brine reservoirs continue to be included in disturbed performance scenarios (DP).

SCR-4.1.1.2.2 Screening Argument

SCR-4.1.1.2.3

The stratigraphy and geology of the region around the WIPP, including the distribution and characteristics of pressurized brine reservoirs in the Castile, are discussed in detail in the CCA, Chapter 2.0, Section 2.1.3. The stratigraphy of the geological formations in the region of the WIPP is accounted for in PA calculations through the setup of the model geometries (Appendix PA-2014, Section PA-4.2.1). The presence of brine reservoirs is accounted for in the treatment of inadvertent drilling (Appendix PA-2014, Section PA-4.2.10).

SCR-4.1.2 Tectonics

SCR-4.1.2.1	**FEP Numbers:**	N3, N4, and N5
	FEP Titles:	*Changes in Regional Stress* (N3) *Regional Tectonics* (N4) *Regional Uplift and Subsidence* (N5)

SCR-4.1.2.1.1 Screening Decision: SO-C

The effects of *Regional Tectonics*, *Regional Uplift* and *Subsidence*, and *Change in Regional Stress* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.1.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.2.1.3 Screening Argument

Regional tectonics encompasses two related issues of concern: the overall level of regional stress and whether any significant changes in regional stress might occur.

The tectonic setting and structural features of the area around the WIPP are described in the CCA, Chapter 2.0, Section 2.1.5. In summary, there is no geological evidence for Quaternary regional tectonics in the Delaware Basin. The eastward tilting of the region has been dated as mid-Miocene to Pliocene by King (King 1948, pp. 120–21) and is associated with the uplift of the Guadalupe Mountains to the west. Fault zones along the eastern margin of the basin, where it flanks the Central Basin Platform, were active during the Late Permian. Evidence for this includes the displacement of the Rustler Formation (hereafter referred to as the Rustler) observed by Holt and Powers (Holt and Powers 1988, pp. 4–14) and the thinning of the Dewey Lake Redbeds Formation (hereafter referred to as the Dewey Lake) reported by Schiel (Schiel 1994). There is, however, no surface displacement along the trend of these fault zones, indicating that there has been no significant Quaternary movement. Other faults identified within the evaporite sequence of the Delaware Basin are inferred by Barrows' figures in Borns et al. (Borns et al. 1983, pp. 58–60) to be the result of salt deformation rather than regional tectonic processes. According to Muehlberger, Belcher, and Goetz (1978, p. 338), the nearest faults on which Quaternary movement has been identified lie to the west of the Guadalupe Mountains and are of minor regional significance. The effects of regional tectonics and changes in regional stress have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

There are no reported stress measurements from the Delaware Basin, but a low–level, regional stress regime with low deviatoric stress has been inferred from the geological setting of the area (see the CCA, Chapter 2.0, Section 2.1.5). The inferred low level of regional stress and the lack of Quaternary tectonic activity indicate that regional tectonics and any changes in regional stress will be minor and therefore of low consequence to the performance of the disposal system. Even if rates of regional tectonic movement experienced over the past 10 million yrs continue, the extent of regional uplift and subsidence over the next 10,000 yrs would only be approximately 1 meter (m) (about several feet [ft]]). This amount of uplift or subsidence would not lead to a breach of the Salado because the salt would deform plastically to accommodate this slow rate of movement. Uniform regional uplift or a small increase in regional dip consistent with this past rate could give rise to downcutting by rivers and streams in the region. The extent of this downcutting would be little more than the extent of uplift, and reducing the overburden by 1 or 2 m would have no significant effect on groundwater flow or contaminant transport in units above or below the Salado. Thus, the effects of regional uplift and subsidence have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.1.2.1.4 Tectonic Setting and Site Structural Features

The DOE has screened out, on the basis of either probability or consequence or both, all tectonic, magmatic, and structural processes. The screening discussions can be found in the CCA, Appendix SCR. The information needed for this screening is included here and covers (1) regional tectonic processes such as subsidence, uplift, and basin tilting; (2) magmatic processes such as igneous intrusion and events such as volcanism; and (3) structural processes such as faulting and loading and unloading of the rocks because of long-term sedimentation or erosion. Discussions of structural events, such as earthquakes, are considered to the extent that they may create new faults or activate old faults. The seismicity of the area is considered in the CCA, Chapter 2.0, Section 2.6 for the purposes of determining seismic design parameters for the facility.

SCR-4.1.2.1.5 Tectonics

The processes and features included in this section are those more traditionally considered part of tectonics–processes that develop the broad-scale features of the earth. Salt dissolution is a different process that can develop some features resembling those of tectonics.

Most broad-scale structural elements of the area around the WIPP developed during the Late Paleozoic (see the CCA, Appendix GCR, pp. 3-58 through 3-77). There is little historical or geological evidence of significant tectonic activity in the vicinity, and the level of stress in the region is low. The entire region tilted slightly during the Tertiary, and activity related to Basin and Range tectonics formed major structures southwest of the area. Seismic activity is specifically addressed in a separate section.

Broad subsidence began in the area as early as the Ordovician, developing a sag called the Tobosa Basin. By Late Pennsylvanian to Early Permian time, the Central Basin Platform developed (see the CCA, Chapter 2.0, Figure 2-19), separating the Tobosa Basin into two parts: the Delaware Basin to the west and the Midland Basin to the east. The Permian Basin refers to the collective set of depositional basins in the area during the Permian Period. Southwest of the Delaware Basin, the Diablo Platform began developing either in the Late Pennsylvanian or Early Permian. The Marathon Uplift and Ouachita tectonic belt limited the southern extent of the Delaware Basin.

According to Brokaw et al. (Brokaw et al. 1972, p. 30), pre-Ochoan sedimentary rocks in the Delaware Basin show evidence of gentle downwarping during deposition, while Ochoan and younger rocks do not. A relatively uniform eastward tilt, generally from about 14 to 19 meters per kilometer (m/km) (75 to 100 ft per mile [ft/mi]), has been superimposed on the sedimentary sequence. King (King 1948, pp. 108 and 121) generally attributes the uplift of the Guadalupe and Delaware mountains along the west side of the Delaware Basin to the later Cenozoic, though he also notes that some faults along the west margin of the Guadalupe Mountains have displaced Quaternary gravels.

King (King 1948, p. 144) also infers the uplift from the Pliocene-age deposits of the Llano Estacado. Subsequent studies of the Ogallala of the Llano Estacado show that it varies in age from Miocene (about 12 million yrs before present) to Pliocene (Hawley 1993). This is the most likely range for uplift of the Guadalupe Mountains and broad tilting to the east of the Delaware Basin sequence.

Analysis of the present regional stress field indicates that the Delaware Basin lies within the Southern Great Plains stress province. This province is a transition zone between the extensional stress regime to the west and the region of compressive stress to the east. An interpretation by Zoback and Zoback (Zoback and Zoback 1991, p. 350) of the available data indicates that the level of stress in the Southern Great Plains stress province is low. Changes to the tectonic setting, such as the development of subduction zones and a consequent change in the driving forces, would take much longer than 10,000 yrs to occur.

To the west of the Southern Great Plains province is the Basin and Range province, or Cordilleran Extension province, where according to Zoback and Zoback (Zoback and Zoback 1991, pp. 348–51) normal faulting is the characteristic style of deformation. The eastern boundary of the Basin and Range province is marked by the Rio Grande Rift. Sanford, Jakasha, and Cash (Sanford, Jakasha, and Cash 1991, p. 230) note that, as a geological structure, the Rift extends beyond the relatively narrow geomorphological feature seen at the surface, with a magnetic anomaly at least 500 km (300 mi) wide. On this basis, the Rio Grande Rift can be regarded as a system of axial grabens along a major north-south trending structural uplift (a continuation of the Southern Rocky Mountains). The magnetic anomaly extends beneath the Southern Great Plains stress province, and regional-scale uplift of about 1,000 m (3,300 ft) over the past 10 million yrs also extends into eastern New Mexico.

To the east of the Southern Great Plains province is the large Mid-Plate province that encompasses central and eastern regions of the conterminous United States and the Atlantic basin west of the Mid-Atlantic Ridge. The Mid-Plate province is characterized by low levels of paleo- and historic seismicity. Where Quaternary faulting has occurred, it is generally strike-slip and appears to be associated with the reactivation of older structural elements.

Zoback et al. (Zoback et al. 1991) report no stress measurements from the Delaware Basin. The stress field in the Southern Great Plains stress province has been defined from borehole measurements in west Texas and from volcanic lineaments in northern New Mexico. These measurements were interpreted by Zoback and Zoback (Zoback and Zoback 1991, p. 353) to indicate that the least principal horizontal stress is oriented north-northeast and south-southwest and that most of the province is characterized by an extensional stress regime.

There is an abrupt change between the orientation of the least principal horizontal stress in the Southern Great Plains and the west-northwest orientation of the least principal horizontal stress characteristic of the Rio Grande Rift. In addition to the geological indications of a transition zone as described above, Zoback and Zoback (Zoback and Zoback 1980, p. 6134) point out that there is also evidence for a sharp boundary between these two provinces. This is reinforced by the change in crustal thickness from about 40 km (24 mi) beneath the Colorado Plateau to about 50 km (30 mi) or more beneath the Southern Great Plains east of the Rio Grande Rift. The base of the crust within the Rio Grande Rift is poorly defined but is shallower than that of the Colorado Plateau (Thompson and Zoback 1979, p. 152). There is also markedly lower heat flow in the Southern Great Plains (typically < 60 m W m^{-2}) reported by Blackwell, Steele, and Carter (1991, p. 428) compared with that in the Rio Grande Rift (typically > 80 m W m^{-2}) reported by Reiter, Barroll, and Minier (Reiter, Barroll, and Minier 1991, p. 463).

On the eastern boundary of the Southern Great Plains province, there is only a small rotation in the direction of the least principal horizontal stress. There is, however, a change from an extensional, normal faulting regime to a compressive, strike-slip faulting regime in the Mid-Plate province. According to Zoback and Zoback (Zoback and Zoback 1980, p. 6134), the available data indicate that this change is not abrupt and that the Southern Great Plains province can be viewed as a marginal part of the Mid-Plate province.

SCR-4.1.3 Structural FEPs

SCR-4.1.3.1 Deformation

SCR-4.1.3.1.1	**FEP Numbers:**	**N6 and N7**
	FEP Titles:	**Salt Deformation (N6)**
		Diapirism (N7)

SCR-4.1.3.1.1.1 Screening Decision: SO-P

Natural *Salt Deformation* and *Diapirism* at the WIPP site over the next 10,000 yrs on a scale severe enough to significantly affect performance of the disposal system have been eliminated from PA calculations on the basis of low probability of occurrence.

SCR-4.1.3.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.3.1.1.3 Screening Argument

Some of the evaporites in the northern Delaware Basin have been deformed and it has been proposed that the likely mechanism for deformation is gravity foundering of the more dense anhydrites in less dense halite (e.g., Anderson and Powers 1978; Jones 1981; Borns et al. 1983; Borns 1987). Diapirism occurs when the deformation is penetrative, i.e., halite beds disrupt overlying anhydrites. As Anderson and Powers (Anderson and Powers 1978) suggested, this may have happened northeast of the WIPP at the location of drillhole ERDA-6. This is the only location where diapirism has been suggested for the evaporites of the northern Delaware Basin. The geologic situation suggests that deformation occurred before the Miocene-Pliocene Ogallala Formation was deposited (Jones 1981). Mechanical modeling is consistent with salt deformation occurring over about 700,000 yrs to form the deformed features known in the northern part of the WIPP site (Borns et al. 1983). The DOE drew the conclusion that evaporites at the WIPP site deform too slowly to affect performance of the disposal system.

Because brine reservoirs appear to be associated with deformation, Powers et al. (Powers et al. 1996) prepared detailed structure elevation maps of various units from the base of the Castile upward through the evaporites in the northern Delaware Basin. Drillholes are far more numerous for this study than at the time of the study by Anderson and Powers (Anderson and Powers 1978). Subdivisions of the Castile appear to be continuous in the vicinity of ERDA-6 and at ERDA-6. There is little justification for interpreting diapiric piercement at that site. The location and distribution of evaporite deformation in the area of the WIPP site is similar to that proposed by earlier studies (e.g., Anderson and Powers 1978; Borns et al. 1983; Borns and Shaffer 1985).

Surface domal features at the northwestern end of Nash Draw were of undetermined origin prior to WIPP investigations (e.g., Vine 1963), but extensive geophysical studies were conducted of these features as part of early WIPP studies (see Powers 1996). Two of the domal features were drilled, demonstrating that they had a solution-collapse origin (breccia pipes) and were not related in any way to salt diapirism (Snyder and Gard 1982).

A more recent study of structure for the Culebra Dolomite Member of the Rustler Formation (hereafter referred to as the Culebra) (Powers 2003) shows that the larger deformation associated with deeper units is reflected by the Culebra, although the structural relief is muted. In addition, evaporite deformation in the northern part of the WIPP site, associated with the area earlier termed the “disturbed zone” (Powers et al. 1978), is hardly observable on a map of Culebra structure (Powers 2003). There is no evidence of more recent deformation at the WIPP site based on such maps.

Deformed salt in the lower Salado and upper strata of the Castile has been encountered in a number of boreholes around the WIPP site; the extent of existing salt deformation is summarized in the CCA, Chapter 2.0, Section 2.1.6.1, and further detail is provided in the CCA, Appendix DEF.

A number of mechanisms may result in salt deformation: in massive salt deposits, buoyancy effects or diapirism may cause salt to rise through denser, overlying units; and in bedded salt with anhydrite or other interbeds, gravity foundering of the interbeds into the halite may take place. Results from rock mechanics modeling studies (see the CCA, Appendix DEF) indicate that the time scale for the deformation process is such that significant natural deformation is unlikely to occur at the WIPP site over any time frame significant to waste isolation. Thus, natural salt deformation and diapirism severe enough to alter existing patterns of groundwater flow or the behavior of the disposal system over the regulatory period has been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.3.2 Fracture Development

SCR-4.1.3.2.1 FEP Number: N8
FEP Title: Formation of Fractures

SCR-4.1.3.2.1.1 Screening Decision: SO-P, UP (Repository)

Formation of Fractures has been eliminated from PA calculations on the basis of a low probability of occurrence over 10,000 yrs. The *Formation of Fractures* near the repository is accounted for in PA through treatment of the DRZ.

SCR-4.1.3.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.3.2.1.3 Screening Argument

The formation of fractures requires larger changes in stress than are required for changes to the properties of existing fractures to overcome the shear and tensile strength of the rock. It has been concluded from the regional tectonic setting of the Delaware Basin that no significant changes in regional stress are expected over the regulatory period. The EPA agrees that fracture formation in the Rustler is likely a result of halite dissolution and subsequent overlying unit fracturing loading/unloading, as well as the syn- and postdepositional processes. Intraformational postdepositional dissolution of the Rustler has been ruled out as a major contributor to Rustler salt distribution and thus to new fracture formation based on work by Holt and Powers in the CCA (Appendix DEF, Section DEF3.2) and Powers and Holt (Powers and Holt 1999 and Powers and Holt 2000), who believe that depositional facies and syndepositional dissolution account for most of the patterns on halite distribution in the Rustler. The argument against developing new fractures in the Rustler during the regulatory period appears reasonable. The formation of new fracture sets in the Culebra has therefore been eliminated from PA calculations on the basis of a low probability of occurrence over 10,000 yrs.

Repository-induced fracturing of the DRZ and Salado interbeds is accounted for in PA calculations.

A mechanism such as salt diapirism could develop fracturing in the Salado, but there is little evidence of diapirism in the Delaware Basin. Salt deformation has occurred in the vicinity of the WIPP, and fractures have developed in deeper Castile anhydrites as a consequence. Deformation rates are slow, and it is highly unlikely that this process will induce significant new fractures in the Salado during the regulatory time period. Surface domal features at the northwestern end of Nash Draw were of undetermined origin prior to WIPP investigations (e.g., Vine 1963), but extensive geophysical studies were conducted of these features as part of early WIPP studies (see Powers 1996). Two of the domal features were drilled, demonstrating that they had a solution-collapse origin (breccia pipes) and were not related in any way to salt diapirism (Snyder and Gard 1982).

SCR-4.1.3.2.2 FEP Number: N9
FEP Title: Changes in Fracture Properties

SCR-4.1.3.2.2.1 Screening Decision: SO-C, UP (near repository)

Naturally induced *Changes in Fracture Properties* that may affect groundwater flow or radionuclide transport in the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. *Changes in Fracture Properties* near the repository are accounted for in PA calculations through treatment of the DRZ.

SCR-4.1.3.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.3.2.2.3 Screening Argument

Groundwater flow in the region of the WIPP and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport will be influenced by fracture characteristics. Changes in fracture properties could arise through natural changes in the local stress field; for example, through tectonic processes, erosion or sedimentation changing the amount of overburden, dissolution of soluble minerals along beds in the Rustler or upper Salado, or dissolution or precipitation of minerals in fractures.

Tectonic processes and features (changes in regional stress [N3]; tectonics [N4]; regional uplift and subsidence [N5]; salt deformation [N6]; diapirism [N7]) have been screened out of PA. These processes are not expected to significantly change the character of fractures during the regulatory period.

Surface erosion or deposition (e.g., N41–N49) are not expected to significantly change the overburden on the Culebra during the regulatory period. The relationship between Culebra transmissivity and depth is significant (Holt and Yarbrough 2002; Holt and Powers 2002), but the potential change to Culebra transmissivity based on deposition or erosion from these processes over the regulatory period is insignificant.

Shallow dissolution (N16), where soluble beds from the upper Salado or Rustler are removed by groundwater, has been extensively considered. There are no direct effects on the Salado at depths of the repository. Extensive study of the upper Salado and Rustler halite units (Holt and Powers 1988; the CCA, Appendix FAC; Powers and Holt 1999 and Powers and Holt 2000; Powers 2003) indicates little potential for dissolution at the WIPP site during the regulatory period. Existing fracture properties are expressed through the relationship between Culebra transmissivity values and geologic factors at and near the WIPP site (Holt and Yarbrough 2002; Holt and Powers 2002, p. 215). These have been incorporated into the transmissivity values for the CRA-2009 Performance Assessment Baseline Calculation (PABC).

Mineral precipitation within fractures (N22) is expected to be beneficial to performance, and it has been screened out on the basis of low consequence. Natural dissolution of fracture fillings within the Culebra is incorporated within FEP N16 (Shallow Dissolution). There is no new information on the distribution of fracture fillings within the Culebra. The effects of fracture fillings are also expected to be represented in the distribution of Culebra transmissivity values around the WIPP site and are thus incorporated into PA.

Repository-induced fracturing of the DRZ and Salado interbeds is accounted for in PA calculations (UP), and is discussed further in FEPs W18 and W19.

SCR-4.1.3.2.3 **FEP Numbers:** N10 and N11

FEP Titles: *Formation of New Faults* (N10)
Fault Movement (N11)

SCR-4.1.3.2.3.1 Screening Decision: SO-P

Naturally induced *Fault Movement* and *Formation of New Faults* of sufficient magnitude to significantly affect the performance of the disposal system have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.1.3.2.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.3.2.3.3 Screening Argument

Faults are present in the Delaware Basin in both the units underlying the Salado and in the Permian evaporite sequence (see the CCA, Section 2.1.5.3). According to Powers et al. (Powers et al. 1978 included in the CCA, Appendix GCR), there is evidence that movement along faults within the pre-Permian units affected the thickness of Early Permian strata, but these faults did not exert a structural control on the deposition of the Castile, the Salado, or the Rustler. Fault zones along the margins of the Delaware Basin were active during the Late Permian Period. Along the eastern margin, where the Delaware Basin flanks the Central Basin Platform, Holt and Powers (Holt and Powers 1988; also included in the CCA, Appendix FAC) note that there is displacement of the Rustler, and Schiel (Schiel 1994) notes that there is thinning of the Dewey Lake. There is, however, no surface displacement along the trend of these fault zones, indicating that there has been no significant Quaternary movement. Muehlberger et al. (Muehlberger et al. 1978, p. 338) note that the nearest faults on which Quaternary movement has been identified lie to the west of the Guadalupe Mountains.

The WIPP is located in an area of tectonic quiescence. Seismic monitoring conducted for the WIPP since the CCA continues to record small events at distance from the WIPP, and these events are mainly in areas associated with resource production (see Section SCR-4.1.3.2.4.2 for more information on seismic events in the area). The absence of Quaternary fault scarps and the general tectonic setting and understanding of its evolution indicate that large-scale, tectonically induced fault movement within the Delaware Basin can be eliminated from PA calculations on the basis of low probability over 10,000 yrs. The stable tectonic setting also allows the formation of new faults within the basin over the next 10,000 yrs to be eliminated from PA calculations on the basis of low probability of occurrence.

Evaporite dissolution at or near the WIPP site has the potential for developing fractures in the overlying beds. Three zones with halite (top of Salado, M1/H1 of the Los Medaños Member, and M2/H2 of the Los Medaños Member) underlie the Culebra at the site (Powers 2003). The upper Salado is present across the site, and there is no indication that dissolution of this area will occur in the regulatory period or cause faulting at the site. The Los Medaños units show both mudflat facies and halite-bearing facies within or adjacent to the WIPP site (Powers 2003). Although the distribution of halite in the Rustler is mainly the result of depositional facies and syndepositional dissolution (Holt and Powers 1988; Powers and Holt 1999 and Powers and Holt 2000), the possibility of past or future halite dissolution along the margins cannot be ruled out (Holt and Powers 1988; Beauheim and Holt 1990). If halite in the lower Rustler has been dissolved along the depositional margin, it has not occurred recently or has been of no consequence, as there is no indication on the surface or in Rustler structure of new (or old) faults in this area (e.g., Powers et al. 1978, Powers 2003).

The absence of Quaternary fault scarps and the general tectonic setting and understanding of its evolution indicate that large-scale, tectonically induced fault movement within the Delaware Basin can be eliminated from PA calculations on the basis of low probability over 10,000 yrs. The stable tectonic setting also allows the formation of new faults within the basin over the next 10,000 yrs to be eliminated from PA calculations on the basis of low probability of occurrence.

SCR-4.1.3.2.4 FEP Number: N12
FEP Title: *Seismic Activity*

SCR-4.1.3.2.4.1 Screening Decision: UP

The post-closure effects of *Seismic Activity* on the repository and the DRZ are accounted for in PA calculations.

SCR-4.1.3.2.4.2 Summary of New Information

Since the CCA, a much more rigorous seismic monitoring system has been developed by the New Mexico Institute of Mining and Technology (NMIMT). This enhanced monitoring network has greatly increased the sensitivity and detection capability of previous systems. Beginning in 2007, the Delaware Basin Drilling Surveillance Program (DBDSP) also improved its seismic database, allowing the identification and incorporation of data previously unavailable. Using this expanded database, the DBDSP identified 703 seismic events recorded within approximately 300 km (187 mi) from the WIPP site, most of which (85%) occurred in close proximity to the Dagger Draw gas field, during the 2002 – 2007 timeframe. During the current CRA-2014 monitoring period (October 2007 through December 2012) there were 543 seismic events recorded within approximately 300 km (187 mi) of the WIPP site. One notable seismic event occurred on March 18, 2012, with a magnitude of 2.4. This seismic event was associated with a potash mine roof fall. This event occurred 14 km (9 mi) southwest of the WIPP site (Callicoat 2013). No damage was identified at the WIPP site. With the continued collection of additional data, it is increasingly clear that the overwhelming majority of these seismic events are anthropogenic in nature.

SCR-4.1.3.2.4.3 Screening Argument

The following subsections present the screening argument for seismic activity (groundshaking).

SCR-4.1.3.2.4.4 Causes of Seismic Activity

Seismic activity describes transient ground motion that may be generated by several energy sources. There are two possible causes of seismic activity that could potentially affect the WIPP site: natural and human-induced. Natural seismic activity is caused by fault movement (earthquakes) when the buildup of strain in rock is released through sudden rupture or movement. Human-induced seismic activity may result from a variety of surface and subsurface activities, such as explosions (H19 and H20), mining (H13, H14, H58, and H59), fluid injection (H28), and fluid withdrawal (H25).

SCR-4.1.3.2.4.5 Groundshaking

Ground vibration and the consequent shaking of buildings and other structures are the most obvious effects of seismic activity. Once the repository and shafts have been sealed, however, existing surface structures will be dismantled. Postclosure PAs are concerned with the effects of seismic activity on the closed repository.

In regions of low and moderate seismic activity, such as the Delaware Basin, rocks behave elastically in response to the passage of seismic waves, and there are no long-term changes in rock properties. The effects of earthquakes beyond the DRZ have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. An inelastic response, such as cracking, is only possible where there are free surfaces, as in the roof and walls of the repository prior to closure by creep. Seismic activity could, therefore, have an effect on the properties of the DRZ.

An assessment of the extent of damage in underground excavations caused by groundshaking depends largely on observations from mines and tunnels. Because such excavations tend to take place in rock types more brittle than halite, these observations cannot be related directly to the behavior of the WIPP. According to Wallner (Wallner 1981, p. 244), the DRZ in brittle rock types is likely to be more highly fractured and hence more prone to spalling and rockfalls than an equivalent zone in salt. Relationships between groundshaking and subsequent damage observed in mines will therefore be conservative with respect to the extent of damage induced at the WIPP by seismic activity.

Dowding and Rozen (Dowding and Rozen 1978) classified damage in underground structures following seismic activity and found that no damage (cracks, spalling, or rockfalls) occurred at accelerations below 0.2 gravities (g) and that only minor damage occurred at accelerations up to 0.4 g. Lenhardt (Lenhardt 1988, p. 392) showed that a magnitude 3 earthquake would have to be within 1 km (0.6 mi) of a mine to result in falls of loose rock. The risk of seismic activity in the region of the WIPP reaching these thresholds is discussed below.

SCR-4.1.3.2.4.6 Seismic Risk in the Region of the WIPP

Prior to the introduction of a seismic monitoring network in 1960, most recorded earthquakes in New Mexico were associated with the Rio Grande Rift, although small earthquakes were detected in other parts of the region. In addition to continued activity in the Rio Grande Rift, the instrumental record has shown a significant amount of seismic activity originating from the Central Basin Platform and a number of small earthquakes in the Los Medaños area. Seismic activity in the Rio Grande Rift is associated with extensional tectonics in that area. Seismic activity in the Central Basin Platform may be associated with natural earthquakes, but there are also indications that this activity occurs in association with oil-field activities such as fluid injection. Small earthquakes in the Los Medaños region have not been precisely located, but may be the result of mining activity in the region. The CCA, Chapter 2.0, Section 2.6.2 contains additional discussion of seismic activity and risk in the WIPP region.

The instrumental record was used as the basis of a seismic risk study primarily intended for design calculations of surface facilities rather than for postclosure PAs. The use of this study to define probable ground accelerations in the WIPP region over the next 10,000 yrs is based on the assumptions that hydrocarbon extraction and potash mining will continue in the region and that the regional tectonic setting precludes major changes over the next 10,000 yrs.

Three source regions were used in calculating seismic risk: the Rio Grande Rift, the Central Basin Platform, and part of the Delaware Basin province (including the Los Medaños). Using conservative assumptions about the maximum magnitude event in each zone, the study indicated a return period of about 10,000 yrs (annual probability of occurrence of 10^{-4}) for events producing ground accelerations of 0.1 g. Ground accelerations of 0.2 g would have an annual probability of occurrence of about 5×10^{-6}.

The results of the seismic risk study and the observations of damage in mines caused by groundshaking give an estimated annual probability of occurrence of between 10^{-8} and 10^{-6} for events that could increase the permeability of the DRZ. The DRZ is accounted for in PA calculations as a zone of permanently high permeability (see Appendix PA-2014, Section PA-4.2.4); this treatment is considered to account for the effects of any potential seismic activity.

SCR-4.1.4 Crustal Process

SCR-4.1.4.1 FEP Number: N13
FEP Title: *Volcanic Activity*

SCR-4.1.4.1.1 Screening Decision: SO-P

Volcanic Activity has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.1.4.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.4.1.3 Screening Argument

The Paleozoic and younger stratigraphic sequences within the Delaware Basin are devoid of locally derived volcanic rocks. Volcanic ashes (dated at 13 million yrs and 0.6 million yrs) do occur in the Gatuña Formation (hereafter referred to as the Gatuña), but these are not locally derived. Within eastern New Mexico and northern, central, and western Texas, the closest Tertiary volcanic rocks with notable areal extent or tectonic significance to the WIPP are approximately 160 km (100 mi) to the south in the Davis Mountains volcanic area. The closest Quaternary volcanic rocks are 250 km (150 mi) to the northwest in the Sacramento Mountains. No volcanic rocks are exposed at the surface within the Delaware Basin.

Volcanic activity is associated with particular tectonic settings: constructive and destructive plate margins, regions of intraplate rifting, and isolated hot-spots in intraplate regions. The tectonic setting of the WIPP site and the Delaware Basin is remote from plate margins, and the absence of past volcanic activity indicates the absence of a major hot spot in the region. Intraplate rifting has taken place along the Rio Grande some 200 km (120 mi) west of the WIPP site during the Tertiary and Quaternary Periods. Igneous activity along this rift valley is comprised of sheet lavas intruded on by a host of small-to-large plugs, sills, and other intrusive bodies. However, the geological setting of the WIPP site within the large and stable Delaware Basin allows volcanic activity in the region of the WIPP repository to be eliminated from performance calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.4.2 **FEP Number:** N14
FEP Title: *Magmatic Activity*

SCR-4.1.4.2.1 Screening Decision: SO-C

The effects of *Magmatic Activity* have been eliminated from the PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.1.4.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.4.2.3 Screening Argument

Magmatic activity is defined as the subsurface intrusion of igneous rocks into country rock. Deep intrusive igneous rocks crystallize at depths of several kilometers (several miles) and have no surface or near-surface expression until considerable erosion has taken place. Alternatively, intrusive rocks may form from magma that has risen to near the surface or in the vents that give rise to volcanoes and lava flows. Magma near the surface may be intruded along subvertical and subhorizontal discontinuities (forming dikes and sills, respectively), and magma in volcanic vents may solidify as plugs. The formation of such features close to a repository or the existence of a recently intruded rock mass could impose thermal stresses, inducing new fractures or altering the hydraulic characteristics of existing fractures.

The principal area of magmatic activity in New Mexico is the Rio Grande Rift, where extensive intrusions occurred during the Tertiary and Quaternary Periods. The Rio Grande Rift, however, is in a different tectonic province than the Delaware Basin, and its magmatic activity is related to the extensional stress regime and high heat flow in that region.

Within the Delaware Basin, there is a single identified outcrop of a lamprophyre dike about 70 km (40 mi) southwest of the WIPP (see the CCA, Chapter 2.0, Section 2.1.5.4 and the CCA, Appendix GCR for more detail). Closer to the WIPP site, similar rocks have been exposed within potash mines some 15 km (10 mi) to the northwest, and igneous rocks have been reported from petroleum exploration boreholes. Material from the subsurface exposures has been dated at around 35 million yrs. Some recrystallization of the host rocks took place alongside the intrusion, and there is evidence that minor fracture development and fluid migration also occurred along the margins of the intrusion. However, the fractures have been sealed, and there is no evidence that the dike acted as a conduit for continued fluid flow.

Aeromagnetic surveys of the Delaware Basin have shown anomalies that lie on a linear southwest-northeast trend that coincides with the surface and subsurface exposures of magmatic rocks. There is a strong indication, therefore, of a dike or a closely related set of dikes extending for at least 120 km (70 mi) across the region (see the CCA, Chapter 2.0, Section 2.1.5.4). The aeromagnetic survey conducted to delineate the dike showed a magnetic anomaly that is several kilometers (several miles) wide at depth and narrows to a thin trace near the surface. This pattern is interpreted as the result of an extensive dike swarm at depths of less than approximately 4.0 km (2.5 mi) near the Precambrian basement, from which a limited number of dikes have extended towards the surface.

Magmatic activity has taken place in the vicinity of the WIPP site in the past, but the igneous rocks have cooled over a long period. Any enhanced fracturing or conduits for fluid flow have been sealed by salt creep and mineralization. Continuing magmatic activity in the Rio Grande Rift is too remote from the WIPP location to be of consequence to the performance of the disposal system. Thus, the effects of magmatic activity have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.1.4.2.4 **FEP Number:** N15
FEP Title: *Metamorphic Activity*

SCR-4.1.4.2.4.1 Screening Decision: SO-P

Metamorphic Activity has been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.4.2.4.1 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.4.2.4.2 Screening Argument

Metamorphic activity, that is, solid-state recrystallization changes to rock properties and geologic structures through the effects of heat and/or pressure, requires depths of burial much greater than the depth of the repository. Regional tectonics that would result in the burial of the repository to the depths at which the repository would be affected by metamorphic activity have been eliminated from PA calculations on the basis of low probability of occurrence; therefore, metamorphic activity has also been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.5 Geochemical Processes

SCR-4.1.5.1 FEP Number: N16 FEP Title: *Shallow Dissolution* (including lateral dissolution)

SCR-4.1.5.1.1 Screening Decision: UP

Shallow Dissolution is accounted for in PA calculations.

SCR-4.1.5.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.5.1.3 Screening Argument

This section discusses a variety of styles of dissolution that have been active in the region of the WIPP or in the Delaware Basin. A distinction has been drawn between shallow dissolution involving circulation of groundwater, mineral dissolution in the Rustler and at the top of the Salado in the region of the WIPP, and deep dissolution taking place in the Castile and the base of the Salado. Dissolution will initially enhance porosities, but continued dissolution may lead to compaction of the affected units with a consequent reduction in porosity. Compaction may result in fracturing of overlying brittle units and increased permeability. Extensive dissolution may create cavities (karst) and result in the total collapse of overlying units. This topic is discussed further in the CCA, Chapter 2.0, Section 2.1.6.2.

SCR-4.1.5.1.4 Shallow Dissolution

In the region around the WIPP, shallow dissolution by groundwater flow has removed soluble minerals from the upper Salado as well as the Rustler to form Nash Draw; extensive solution within the closed draw has created karst features including caves and dolines in the sulfate beds of the Rustler (see Lee 1925; Bachman 1980, Bachman 1985, and Bachman 1987a). An alluvial doline drilled at WIPP 33, about 850 m (2800 ft) west of the WIPP site boundary, is the nearest karst feature known in the vicinity of the site. Upper Salado halite dissolution in Nash Draw resulted in fracture propagation upward through the overlying Rustler (Holt and Powers 1988). The margin of dissolution of halite from the upper Salado has commonly been placed west of the

WIPP site, near, but east of, Livingston Ridge, the eastern boundary of Nash Draw. Halite occurs in the Rustler east of Livingston Ridge, with the margin generally progressively eastward in higher stratigraphic units (e.g., Snyder 1985; Powers and Holt 1995). The distribution of halite in the Rustler has commonly been attributed to shallow dissolution (e.g., Powers et al. 1978; Lambert 1983; Bachman 1985; Lowenstein 1987). During early studies for the WIPP, the variability of Culebra transmissivity in the vicinity of the WIPP was commonly attributed to the effects of Rustler halite dissolution and changes in fracturing as a consequence.

After a detailed sedimentologic and stratigraphic investigation of WIPP cores, shafts, and geophysical logs from the region around the WIPP, the distribution of halite in the Rustler was attributed to depositional and syndepositional processes rather than postdepositional dissolution (Holt and Powers 1988; Powers and Holt 2000). Rustler exposures in shafts for the WIPP revealed extensive sedimentary structures in clastic units (Holt and Powers 1984, Holt and Powers 1986, and Holt and Powers 1990), and the suite of features in these beds led these investigators (Holt and Powers 1988; Powers and Holt 1990 and Powers and Holt 2000) to reinterpret the clastic units. They conclude that the clastic facies represent mainly mudflat facies tracts adjacent to a salt pan. Although some halite was likely deposited in mudflat areas proximal to the salt pan, it was largely removed by syndepositional dissolution, as indicated by soil structures, soft sediment deformation, bedding, and small-scale vertical relationships (Holt and Powers 1988; Powers and Holt 1990, Powers and Holt 1999 and Powers and Holt 2000). The depositional margins of halite in the Rustler are the likely points for past or future dissolution (e.g., Holt and Powers 1988; Beauheim and Holt 1990). Cores from drillholes at the H-19 drillpad near the Tamarisk Member halite margin show evidence of some dissolution of halite in the Tamarisk (Mercer et al. 1998), consistent with these predictions. The distribution of Culebra transmissivity values is not considered related to dissolution of Rustler halite, and other geological factors (e.g., depth, upper Salado dissolution) correlate well with Culebra transmissivity (e.g., Powers and Holt 1995; Holt and Powers 2002).

Since the CCA was completed, the WIPP has conducted additional work on shallow dissolution, principally of the upper Salado, and its possible relationship to the distribution of transmissivity values for the Culebra as determined through testing of WIPP hydrology wells.

Analysis Plan 088 (AP-088) (Beauheim 2002) noted that potentiometric surface values for the Culebra in many monitoring wells were outside the uncertainty ranges used to calibrate models of steady-state heads for the unit. AP-088 directed the analysis of the relationship between geological factors and values of transmissivity at Culebra wells. The relationship between geological factors, including dissolution of the upper Salado as well as limited dissolution in the Rustler, and Culebra transmissivity has been used to evaluate differences between assuming steady-state Culebra heads and changing heads.

Task 1 for AP-088 (Powers 2003) evaluated geological factors, including shallow dissolution in the vicinity of the WIPP site related to Culebra transmissivity. A much more extensive drillhole geological database was developed than was previously available, utilizing sources of data from WIPP, potash exploration, and oil and gas exploration and development. The principal findings related to shallow dissolution are (1) a relatively narrow zone (~ 200 – 400 m [656 – 1,312 ft] wide) could be defined as the margin of dissolution of the upper Salado in much of the area around the WIPP, (2) the upper Salado dissolution margin commonly underlies surface escarpments such as Livingston Ridge, and (3) there are possible extensions or reentrants of incipient upper Salado dissolution extending eastward from the general dissolution margin. The WIPP site proper is not affected by this process.

Culebra transmissivity correlates well with depth or overburden, which affects fracture apertures (Powers and Holt 1995; Holt and Powers 2002; Holt and Yarbrough 2002). Dissolution of the upper Salado appears to increase transmissivity by one or more orders of magnitude (Holt and Yarbrough 2002). Because there is no indication of upper Salado dissolution at the WIPP site, Holt and Yarbrough (Holt and Yarbrough 2002) did not include this factor for the WIPP site in estimates of base transmissivity values for the WIPP site and surroundings.

The effects of shallow dissolution (including the impacts of lateral dissolution) have been included in PA calculations in the derivation of transmissivity fields for Culebra flow and transport.

SCR-4.1.5.2 **FEP Numbers:** N18, N20, and N21

FEP Titles: *Deep Dissolution* (N18)
Breccia Pipes (N20)
Collapse Breccias (N21)

SCR-4.1.5.2.1 Screening Decision: SO-P

Deep Dissolution and the formation of associated features (for example, solution chimneys or *Breccia Pipes*, *Collapse Breccias*) at the WIPP site have been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.5.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.5.2.3 Screening Argument

This section discusses a variety of styles of dissolution that have been active in the region of the WIPP or in the Delaware Basin. A distinction has been drawn between shallow dissolution, involving circulation of groundwater and mineral dissolution in the Rustler and at the top of the Salado in the region of the WIPP, and deep dissolution taking place in the Castile and the base of the Salado. Dissolution will initially enhance porosities, but continued dissolution may lead to compaction of the affected units with a consequent reduction in porosity. Compaction may result in fracturing of overlying brittle units and increased permeability. Extensive dissolution may create cavities (karst) and result in the total collapse of overlying units. This topic is discussed further in the CCA, Chapter 2.0, Section 2.1.6.2.

SCR-4.1.5.2.4 Deep Dissolution

Deep dissolution is limited to processes involving dissolution of the Castile or basal Salado and features such as breccia pipes (also known as solution chimneys) associated with this process (see the CCA, Chapter 2.0, Section 2.1.6.2). Deep dissolution is distinguished from shallow and lateral dissolution not only by depth, but also by the origin of the water. Dissolution by groundwater from deep water-bearing zones can lead to the formation of cavities. Collapse of overlying beds leads to the formation of collapse breccias if the overlying rocks are brittle, or to deformation if the overlying rocks are ductile. If dissolution is extensive, breccia pipes or solution chimneys may form above the cavity. These pipes may reach the surface or pass upwards into fractures and then into microcracks that do not extend to the surface. Breccia pipes may also form through the downward percolation of meteoric waters, as discussed earlier. Deep dissolution is of concern because it could accelerate contaminant transport through the creation of vertical flow paths that bypass low-permeability units in the Rustler. If dissolution occurred within or beneath the waste panels themselves, there could be increased circulation of groundwater through the waste, as well as a breach of the Salado host rock.

Features identified as being the result of deep dissolution are present along the northern and eastern margins of the Delaware Basin. In addition to features that have a surface expression or that appear within potash mine workings, deep dissolution has been cited by Anderson et al. (Anderson et al. 1972, p. 81) as the cause of lateral variability within evaporite sequences in the lower Salado.

Exposures of the McNutt Potash Member of the Salado within a mine near Nash Draw have shown a breccia pipe containing cemented brecciated fragments of formations higher in the stratigraphic sequence. At the surface, this feature is marked by a dome, and similar domes have been interpreted as dissolution features. The depth of dissolution has not been confirmed, but the collapse structures led Anderson (Anderson 1978, p. 52) and Snyder et al. (Snyder et al. 1982, p. 65) to postulate dissolution of the Capitan Limestone at depth; collapse of the Salado, Rustler, and younger formations; and subsequent dissolution and hydration by downward percolating waters. San Simon Sink (see the CCA, Chapter 2.0, Section 2.1.6.2), some 35 km (20 mi) east-southeast of the WIPP site, has also been interpreted as a solution chimney. Subsidence has occurred there in historical times according to Nicholson and Clebsch (Nicholson and Clebsch 1961, p. 14), suggesting that dissolution at depth is still taking place. Whether this is the result of downward-percolating surface water or deep groundwater has not been confirmed. The association of these dissolution features with the inner margin of the Capitan Reef suggest that they owe their origins, if not their continued development, to groundwaters derived from the Capitan Limestone.

SCR-4.1.5.2.5 Dissolution within the Castile and Lower Salado

The Castile contains sequences of varved anhydrite and carbonate (that is, laminae deposited on a cyclical basis) that can be correlated between several boreholes. On the basis of these deposits, a basin-wide uniformity in the depositional environment of the Castile evaporites was assumed. The absence of varves from all or part of a sequence and the presence of brecciated anhydrite beds have been interpreted by Anderson et al. (Anderson et al.1972) as evidence of dissolution. Holt and Powers (the CCA, Appendix FAC) have questioned the assumption of a uniform depositional environment and contend that the anhydrite beds are lateral equivalents of halite sequences without significant postdepositional dissolution. Wedges of brecciated anhydrite along the margin of the Castile have been interpreted by Robinson and Powers (Robinson and Powers 1987, p. 78) as gravity-driven clastic deposits, rather than the result of deep dissolution.

Localized depressions at the top of the Castile and inclined geophysical marker units at the base of the Salado have been interpreted by Davies (Davies 1983, p. 45) as the result of deep dissolution and subsequent collapse or deformation of overlying rocks. The postulated cause of this dissolution was circulation of undersaturated groundwaters from the Bell Canyon Formation (hereafter referred to as Bell Canyon). Additional boreholes (notably WIPP-13, WIPP-32, and DOE-2) and geophysical logging led Borns and Shaffer (Borns and Shaffer 1985) to conclude that the features interpreted by Davies as being dissolution features are the result of irregularities at the top of Bell Canyon. These irregularities led to localized depositional thickening of the Castile and lower Salado sediments.

SCR-4.1.5.2.6 Collapse Breccias at Basin Margins

Collapse breccias are present at several places around the margins of the Delaware Basin. Their formation is attributed to relatively fresh groundwater from the Capitan Limestone that forms the margin of the basin. Collapse breccias corresponding to features on geophysical records that have been ascribed to deep dissolution have not been found in boreholes away from the margins. These features have been reinterpreted as the result of early dissolution prior to the deposition of the Salado.

SCR-4.1.5.2.7 Summary of Deep Dissolution

Deep dissolution features have been identified within the Delaware Basin, but only in marginal areas underlain by Capitan Reef. There is a low probability that deep dissolution will occur sufficiently close to the waste panels over the regulatory period to affect groundwater flow in the immediate region of the WIPP. Deep dissolution at the WIPP site has therefore been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.1.5.3 **FEP Number:** N22
FEP Title: *Fracture Infill*

SCR-4.1.5.3.1 Screening Decision: SO-C – Beneficial

The effects of *Fracture Infill* have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-4.1.5.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.1.5.3.3 Screening Argument

SCR-4.1.5.3.3.1 Mineralization

Precipitation of minerals as fracture infills can reduce hydraulic conductivities. The distribution of infilled fractures in the Culebra closely parallels the spatial variability of lateral transmissivity in the Culebra. The secondary gypsum veins in the Rustler have not been dated. Strontium isotope studies (Siegel et al. 1991, pp. 5-53 to 5-57) indicate that the infilling minerals are locally derived from the host rock rather than extrinsically derived, and it is inferred that they reflect an early phase of mineralization and are not associated with recent meteoric waters.

Stable isotope geochemistry in the Rustler has also provided information on mineral stabilities in these strata. Both Chapman (Chapman 1986, p. 31) and Lambert and Harvey (Lambert and Harvey 1987, p. 207) imply that the mineralogical characteristics of units above the Salado have been stable or subject to only minor changes under the various recharge conditions that have existed during the past 0.6 million yrs—the period since the formation of the Mescalero caliche and the establishment of a pattern of climate change and associated changes in recharge that led to present-day hydrogeological conditions. No changes in climate are expected other than those experienced during this period, and for this reason, no changes are expected in the mineralogical characteristics other than those expressed by the existing variability of fracture infills and diagenetic textures. Formation of fracture infills will reduce transmissivities and will therefore be of beneficial consequence to the performance of the disposal system.

SCR-4.2 Subsurface Hydrological FEPs

SCR-4.2.1 Groundwater Characteristics

SCR-4.2.1.1	**FEP Numbers:**	N23, N24, N25, and N27
	FEP Titles:	*Saturated Groundwater Flow* (N23) *Unsaturated Groundwater Flow* (N24) *Fracture Flow* (N25) *Effects of Preferential Pathways* (N27)

SCR-4.2.1.1.1 Screening Decision: UP

Saturated Groundwater Flow, Unsaturated Groundwater Flow, Fracture Flow, and Effects of Preferential Pathways are accounted for in PA calculations.

SCR-4.2.1.1.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.2.1.1.3 Screening Argument

Saturated groundwater flow, unsaturated groundwater flow, and fracture flow are accounted for in PA calculations. Groundwater flow is discussed in the CCA, Chapter 2.0, Section 2.2.1; and Chapter 6.0, Section 6.4.5 and Section 6.4.6.

The hydrogeologic properties of the Culebra are also spatially variable. This variability, including the effects of preferential pathways, is accounted for in PA calculations in the estimates of transmissivity and aquifer thickness.

SCR-4.2.1.2 **FEP Number:** N26 **FEP Title:** *Density Effect on Groundwater Flow*

SCR-4.2.1.2.1 Screening Decision: SO-C

Density Effects on Groundwater Flow has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.1.2.3 Screening Argument

The most transmissive unit in the Rustler, and hence the most significant potential pathway for transport of radionuclides to the accessible environment, is the Culebra. The properties of Culebra groundwaters are not homogeneous, and spatial variations in groundwater density (the CCA, Chapter 2.0, Section 2.2.1.4.1.2) could influence the rate and direction of groundwater flow. A comparison of the gravity-driven flow component and the pressure-driven component in the Culebra, however, shows that only in the region to the south of the WIPP are head gradients low enough for density gradients to be significant (Davies 1989, p. 53). Accounting for this variability would rotate groundwater flow vectors towards the east (down-dip) and hence fluid in the high-transmissivity zone would move away from the zone. Excluding brine density variations within the Culebra from PA calculations is therefore a conservative assumption, and density effects on groundwater flow have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.2 Changes in Groundwater Flow

SCR-4.2.2.1 **FEP Number:** N28 **FEP Title:** *Thermal Effects on Groundwater Flow*

SCR-4.2.2.1.1 Screening Decision: SO-C

Natural Thermal Effects on Groundwater Flow have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.2.1.3 Screening Argument

The geothermal gradient in the region of the WIPP has been measured at about 30 degrees centigrade (°C) (54 degrees Fahrenheit [°F]) per kilometer (50 °C [90 °F] per mile). Given the generally low permeability in the region and the limited thickness of units in which groundwater flow occurs (for example, the Culebra), natural convection will be too weak to have a significant effect on groundwater flow. No natural FEPs have been identified that could significantly alter the temperature distribution of the disposal system or give rise to thermal effects on groundwater flow. Such effects have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.2.2 **FEP Number:** N29 **FEP Title:** *Saline Intrusion* (hydrogeological effects)

SCR-4.2.2.2.1 Screening Decision: SO-P

Changes in groundwater flow arising from *Saline Intrusion* have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.2.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.2.2.3 Screening Argument

No natural events or processes have been identified that could result in saline intrusion into units above the Salado or cause a significant increase in fluid density. Natural saline intrusion has therefore been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs. Saline intrusion arising from human events such as drilling into a pressurized brine pocket is discussed in FEPs H21 through H24 (Section SCR-5.2.1.4).

SCR-4.2.2.3 **FEP Number:** N30 **FEP Title:** *Freshwater Intrusion* (hydrogeological effects)

SCR-4.2.2.3.1 Screening Decision: SO-P

Changes in groundwater flow arising from *Freshwater Intrusion* have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.2.2.3.2 Summary

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.2.3.2.1 Screening Argument

A number of FEPs, including climate change, can result in changes in infiltration and recharge (see discussions for FEPs N53 through N55, Section SCR-4.5.3.1). These changes will affect the height of the water table and, hence, could affect groundwater flow in the Rustler through changes in head gradients. The generally low transmissivity of the Dewey Lake and the Rustler, however, will prevent any significant changes in groundwater density from occurring within the Culebra over the timescales for which increased precipitation and recharge are anticipated. No other natural events or processes have been identified that could result in freshwater intrusion into units above the Salado or cause a significant decrease in fluid density. Freshwater intrusion has therefore been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.2.2.4 **FEP Number:** N31 **FEP Title:** *Hydrological Response to Earthquakes*

SCR-4.2.2.4.1 Screening Decision: SO-C

Hydrological Response to Earthquakes has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.2.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.2.4.3 Screening Argument

SCR-4.2.2.4.3.1 Hydrological Effects of Seismic Activity

There are a variety of hydrological responses to earthquakes. Some of these responses, such as changes in surface-water flow directions, result directly from fault movement. Others, such as changes in subsurface water chemistry and temperature, probably result from changes in flow pathways along the fault or fault zone. According to Bredehoeft et al. (Bredehoeft et al. 1987, p. 139), further away from the region of fault movement, two types of changes to groundwater levels may take place as a result of changes in fluid pressure.

- The passage of seismic waves through a rock mass causes a volume change, inducing a transient response in the fluid pressure, which may be observed as a short-lived fluctuation of the water level in wells.

- Changes in volume strain can cause long-term changes in water level. A buildup of strain occurs prior to rupture and is released during an earthquake. The consequent change in fluid pressure may be manifested by the drying up or reactivation of springs some distance from the region of the epicenter.

Fluid-pressure changes induced by the transmission of seismic waves can produce changes of up to several meters (several yards) in groundwater levels in wells, even at distances of thousands of kilometers from the epicenter. These changes are temporary, however, and levels typically return to pre-earthquake levels in a few hours or days. Changes in fluid pressure arising from changes in volume strain persist for much longer periods, but they are only potentially consequential in tectonic regimes where there is a significant buildup of strain. The regional tectonics of the Delaware Basin indicates that such a buildup has a low probability of occurring over the next 10,000 yrs (see FEPs N3 and N4, Section SCR-4.1.2.1).

The expected level of seismic activity in the region of the WIPP will be of low consequence to the performance of the disposal system in terms of groundwater flow or contaminant transport. Changes in groundwater levels resulting from more distant earthquakes will be too short in duration to be significant. Thus, hydrological response to earthquakes has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.2.2.5 **FEP Number:** N32
FEP Title: *Natural Gas Intrusion*

SCR-4.2.2.5.1 Screening decision: SO-P

Changes in groundwater flow arising from *Natural Gas Intrusion* have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.2.2.5.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.2.2.5.2.1 Screening Argument

Hydrocarbon resources are present in formations beneath the WIPP (the CCA, Chapter 2.0, Section 2.3.1.2), and natural gas is extracted from the Morrow Formation. These reserves are, however, some 4,200 m (14,000 ft) below the surface, and no natural events or processes have been identified that could result in natural gas intrusion into the Salado or the units above. Natural gas intrusion has therefore been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.3 Subsurface Geochemical FEPs

SCR-4.3.1 Groundwater Geochemistry

SCR-4.3.1.1 **FEP Number:** N33
FEP Title: *Groundwater Geochemistry*

SCR-4.3.1.1.1 Screening Decision: UP

Groundwater Geochemistry in the hydrological units of the disposal system is accounted for in PA calculations.

SCR-4.3.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.3.1.1.3 Screening Argument

The most important aspect of groundwater geochemistry in the region of the WIPP in terms of chemical retardation and colloid stability is salinity. Groundwater geochemistry is discussed in detail in the CCA, Chapter 2.0, Section 2.2 and Section 2.4 and summarized here. The Delaware Mountain Group, Castile, and Salado contain basinal brines. Waters in the Castile and Salado are at or near halite saturation. Above the Salado, groundwaters are also relatively saline, and groundwater quality is poor in all of the permeable units. Waters from the Culebra vary spatially in salinity and chemistry. They range from saline sodium chloride-rich waters to brackish calcium sulfate-rich waters. In addition, a range of magnesium-to-calcium ratios has been observed, and some waters reflect the influence of potash mining activities, having elevated potassium-to-sodium ratios. Waters from the Santa Rosa are generally of better quality than those from the Rustler. Salado and Castile brine geochemistry is accounted for in PA calculations of the actinide (An) source term (the CCA, Chapter 6.0, Section 6.4.3.4). Culebra brine geochemistry is accounted for in the retardation factors used in PA calculations of actinide transport (see the CCA, Chapter 6.0, Section 6.4.6.2).

SCR-4.3.1.2 **FEP Numbers:** N34 and N38

FEP Titles: *Saline Intrusion* (N34)
Effects of Dissolution (N38)

SCR-4.3.1.2.1 Screening Decision: SO-C

The effects of *Saline Intrusion* and *Dissolution* on groundwater chemistry have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.3.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.3.1.2.3 Screening Argument

Saline intrusion and effects of dissolution are considered together in this discussion because dissolution of minerals such as halite (NaCl), anhydrite ($CaSO_4$), or gypsum ($CaSO_4 \cdot 2H_2O$) (N38) could – in the most extreme case – increase the salinity of groundwaters in the Culebra to levels characteristic of those expected after saline intrusion (N34).

No natural events or processes have been identified that could result in saline intrusion into units above the Salado. Injection of Castile or Salado brines into the Culebra as a result of human intrusion, an anthropogenically induced event, was included in past PA calculations. Laboratory studies carried out to evaluate radionuclide transport in the Culebra following human intrusion produced data that can also be used to evaluate the consequences of natural saline intrusion.

The possibility that dissolution of halite, anhydrite, or gypsum might result in an increase in the salinity of low- to moderate-ionic-strength groundwaters in the Culebra also appears unlikely, despite the presence of halite in the Los Medaños under most of the WIPP site (Siegel and Lambert 1991, Figure 1-13), including the expected Culebra off-site transport pathway (the direction of flow from the point(s) at which brines from the repository would enter the Culebra, flow towards the south or south-southeast, and eventually to the boundary of the WIPP site). (The Los Medaños Member of the Rustler, formerly referred to as the unnamed lower member of the Rustler, underlies the Culebra.) A dissolution-induced increase in the salinity of Culebra groundwaters is unlikely because (1) the dissolution of halite is known to be rapid; (2) (moderate-ionic-strength) groundwaters along the off-site transport pathway (and at many other locations in the Culebra) have had sufficient time to dissolve significant quantities of halite, if this mineral is present in the subjacent Los Medaños and if Culebra fluids have been in contact with it; and (3) the lack of high-ionic-strength groundwaters along the off-site transport pathway (and elsewhere in the Culebra) implies that halite is present in the Los Medaños but Culebra fluids have not contacted it, or that halite is not present in the Los Medaños. Because halite dissolves so rapidly if contacted by undersaturated solutions, this conclusion does not depend on the nature and timing of Culebra recharge (i.e., whether the Rustler has been a closed hydrologic system for several thousand to a few tens of thousands of yrs, or is subject to significant modern recharge).

Nevertheless, saline intrusion would not affect the predicted transport of thorium (Th), uranium (U), plutonium (Pu), and americium (Am) in the Culebra. This is because (1) the laboratory studies that quantified the retardation of Th, U, Pu, and Am for the CCA PA were carried out with both moderate-ionic-strength solutions representative of Culebra groundwaters along the expected off-site transport pathway and high-ionic-strength solutions representative of brines from the Castile and the Salado (Brush 1996; Brush and Storz 1996); and (2) the results obtained with the Castile and Salado brines were – for the most part – used to predict the transport of Pu(III) and Am(III); Th(IV), U(IV), Np(IV), and Pu(IV); and U(VI). The results obtained with the saline solutions were used for these actinide oxidation states because the extent to which saline and Culebra brines will mix along the offsite transport pathway in the Culebra was unclear at the time of the CCA PA; therefore, Brush (Brush 1996) and Brush and Storz (Brush and Storz 1996) recommended that PA use the results that predict less retardation. In the case of Pu(III) and Am(III); Th(IV), U(IV), Np(IV), and Pu(IV); and U(VI), the retardation distribution coefficient (K_ds) obtained with the saline solutions were somewhat lower than those obtained with the Culebra fluids. The K_ds used in the CRA-2014 are the same as used in the CRA-2009 PABC.

Finally, it is important to reiterate that the use of results from laboratory studies with saline solutions to predict radionuclide transport in the Culebra for previous PAs and the CRA-2014 PA implement the effects of saline intrusion caused by human intrusion, not natural saline intrusion. The conclusions that natural saline intrusion is unlikely, that significant dissolution is unlikely, and that these events or processes would have no significant consequence – in the unlikely event that they occur – continue to be valid.

SCR-4.3.1.3

FEP Numbers: N35, N36, and N37
FEP Titles: *Freshwater Intrusion* (Geochemical Effects) (N35)
Change in Groundwater Eh (N36)
Changes in Groundwater pH (N37)

SCR-4.3.1.3.1 Screening Decision: SO-C

The effects of *Freshwater Intrusion* on groundwater chemistry have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. *Changes in Groundwater Eh* and *Changes in Groundwater pH* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.3.1.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.3.1.3.3 Screening Argument

Natural changes in the groundwater chemistry of the Culebra and other units that resulted from saline intrusion or freshwater intrusion could potentially affect chemical retardation and the stability of colloids. Changes in groundwater Eh and groundwater pH could also affect the migration of radionuclides (see FEPs W65 to W70, Section SCR-6.5.5.2, Section SCR-6.5.5.3, Section SCR-6.5.6.1, and Section SCR-6.5.6.2). No natural EPs have been identified that could result in saline intrusion into units above the Salado, and the magnitude of any natural temporal variation from the effects of dissolution on groundwater chemistry, or because of changes in recharge, is likely to be no greater than the present spatial variation. These FEPs related to the effects of future natural changes in groundwater chemistry have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. See Appendix SOTERM-2014, Section 2.3.1 for a discussion of WIPP brine chemistry.

The most likely mechanism for (natural) freshwater intrusion into the Culebra (N35), changes in groundwater Eh (N36), and changes in groundwater pH (N37) is (natural) recharge of the Culebra. (Other FEPs consider possible anthropogenically induced recharge). These three FEPs are closely related because an increase in the rate of recharge could reduce the ionic strength(s) of Culebra groundwaters, possibly enough to saturate the Culebra with (essentially) fresh water, at least temporarily. Such a change in ionic strength could, if enough atmospheric oxygen remained in solution, also increase the Eh of Culebra groundwaters enough to oxidize Pu from the relatively immobile III and IV oxidation states (Pu(III) and Pu(IV)) – the oxidation states expected under current conditions (Brush 1996; Brush and Storz 1996) – to the relatively mobile V and VI oxidation states (Pu(V) and Pu(VI)). Similarly, recharge of the Culebra with freshwater could also change the pH of Culebra groundwaters from the currently observed range of about 6 to 7 to mildly acidic values, thus (possibly) decreasing the retardation of dissolved Pu and Am. (These changes in ionic strength, Eh, and pH could also affect mobilities of Th, U, and neptunium (Np), but the long-term performance of the WIPP is much less sensitive to the mobilities of these radioelements than to those of Pu and Am.)

There is still considerable uncertainty regarding the extent and timing of recharge to the Culebra. Lambert (Lambert 1986), Lambert and Carter (Lambert and Carter 1987), and Lambert and Harvey (Lambert and Harvey 1987) used a variety of stable and radiogenic isotopic-dating techniques to conclude that the Rustler (and the Dewey Lake) have been closed hydrologic systems for several thousand to a few tens of thousands of yrs. In other words, the last significant recharge of the Rustler occurred during the late Pleistocene in response to higher levels of precipitation and infiltration associated with the most recent continental glaciation of North America, and the current flow field in the Culebra is the result of the slow discharge of groundwater from this unit. Other investigators have agreed that it is possible that Pleistocene recharge has contributed to present-day flow patterns in the Culebra, but that current patterns are also consistent with significant current recharge (Haug et al. 1987; Davies 1989). Still others (Chapman 1986 and Chapman 1988) have rejected Lambert's interpretations in favor of exclusively modern recharge, at least in some areas. For example, the low salinity of Hydrochemical Zone B south of the WIPP site could represent dilution of Culebra groundwater with significant quantities of recently introduced meteoric water (see Siegel et al. 1991, pp. 2-57–2-62 and Figure 2-17 for definitions and locations of the four hydrochemical facies in the Culebra in and around the WIPP site).

Past hydrogeological investigations into the cause and effect from observed water-level rises in the Culebra led to a revised groundwater conceptual model (Appendix TFIELD-2014, Section 3.0). Continuing hydrogeological studies have seen responses to precipitation events in Culebra wells. This is not to say, however, that present-day rainfall actually enters the Culebra wherever a pressure response to rainfall is observed. Rather, the rainfall reaches a water table in a higher stratigraphic unit that is in sufficient hydraulic communication with the Culebra to transmit a *pressure* response rapidly. It takes a much longer time for water or dissolved constituents to move through the subsurface than it takes a pressure wave to propagate through a saturated porous medium (Appendix HYDRO-2014, Section 7.1).

However, the justification of this screening decision does not depend on this issue. 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 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.

It is also worth noting that the choice of the most recent glacial maximum as an upper limit for possible climatic changes during the 10,000-year (yr) WIPP regulatory period (Swift et al. 1991;

the CCA, Appendix CLI) established conservative upper limits for precipitation and recharge of the Culebra at the WIPP site. The review by Swift et al. (Swift et al. 1991), later incorporated in the CCA, Appendix CLI, provides evidence that precipitation in New Mexico did not attain its maximum level (about 60-100% of current precipitation) until a few thousand yrs before the last glacial maximum. Swift et al. (Swift et al. 1991) pointed out,

> Prior to the last glacial maximum 22 to 18 ka BP, evidence from mid- Wisconsin faunal assemblages in caves in southern New Mexico, including the presence of extralimital species such as the desert tortoise that are now restricted to warmer climates, suggests warm summers and mild, relatively dry winters (Harris 1987, 1988). Lacustrine evidence confirms the interpretation that conditions prior to and during the glacial advance that were generally drier than those at the glacial maximum. Permanent water did not appear in what was later to be a major lake in the Estancia Valley in central New Mexico until sometime before 24 ka BP (Bachhuber 1989). Late-Pleistocene lake levels in the San Agustin Plains in western New Mexico remained low until approximately 26.4 ka BP, and the $\delta^{18}O$ record from ostracode shells suggests that mean annual temperatures at that location did not decrease significantly until approximately 22 ka BP (Phillips et al. 1992).

Therefore, it is likely that precipitation and recharge did not attain levels characteristic of the most recent glacial maximum until about 70,000 to 75,000 yrs after the last glaciations had begun. High-resolution, deep-sea $\delta^{18}O$ data (and other data) reviewed by Servant (Servant 2001, Figure 1 and Figure 2) support the conclusion that, although the volume of ice incorporated in continental ice sheets can expand rapidly at the start of a glaciation, attainment of maximum volume does not occur until a few thousand or a few tens of thousands of yrs prior to the termination of the approximately 100,000-yr glaciations that have occurred during the last 0.5 to 1 Ma BP. Therefore, it is unlikely that precipitation and recharge will reach their maximum levels during the 10,000-yr regulatory period.

If, on the other hand, significant recharge occurs throughout both phases of the glacial-interglacial cycles, the conclusion that the effects of pluvial and modern recharge are inconsequential (i.e., are already reflected by existing variations in geochemical conditions) is also still valid. The effects of future natural changes in groundwater chemistry have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4 Geomorphological FEPs

SCR-4.4.1 Physiography

SCR-4.4.1.1 **FEP Number:** N39
FEP Title: *Physiography*

SCR-4.4.1.1.1 Screening Decision: UP

Relevant aspects of the *Physiography*, geomorphology, and topography of the region around the WIPP are accounted for in PA calculations.

SCR-4.4.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.4.1.1.3 Screening Argument

Physiography and geomorphology are discussed in detail in the CCA, Chapter 2.0, Section 2.1.4, and are accounted for in the setup of the PA calculations (the CCA, Chapter 6.0, Section 6.4.2).

SCR-4.4.1.2 FEP Number: N40
FEP Title: *Impact of a Large Meteorite*

SCR-4.4.1.2.1 Screening Decision: SO-P

Disruption arising from the *Impact of a Large Meteorite* has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.4.1.3 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.4.1.4 Screening Argument

Meteors frequently enter the earth’s atmosphere, but most of these are small and burn up before reaching the ground. Of those that reach the ground, most produce only small impact craters that would have no effect on the postclosure integrity of a repository 650 m (2,150 ft) below the ground surface. While the depth of a crater may be only one-eighth of its diameter, the depth of the disrupted and brecciated material is typically one-third of the overall crater diameter (Grieve 1987, p. 248). Direct disruption of waste at the WIPP would only occur with a crater larger than 1.8 km (1.1 mi) in diameter. Even if waste were not directly disrupted, the impact of a large meteorite could create a zone of fractured rocks beneath and around the crater. The extent of such a zone would depend on the rock type. For sedimentary rocks, the zone may extend to a depth of half the crater diameter or more (Dence et al. 1977, p. 263). The impact of a meteorite causing a crater larger than 1 km (0.6 mi) in diameter could thus fracture the Salado above the repository.

Geological evidence for meteorite impacts on earth is rare because many meteorites fall into the oceans and erosion and sedimentation serve to obscure craters that form on land. Dietz (Dietz 1961) estimated that meteorites that cause craters larger than 1 km (0.6 mi) in diameter strike the earth at the rate of about one every 10,000 yrs (equivalent to about 2×10^{-13} impacts per square kilometer (km^2) per yr). Using observations from the Canadian Shield, Hartmann (1965, p. 161) estimated a frequency of between 0.8×10^{-13} and 17×10^{-13} impacts/km^2/yr for impacts causing craters larger than 1 km (0.6 mi). Frequencies estimated for larger impacts in studies reported by Grieve (Grieve 1987, p. 263) can be extrapolated to give a rate of about 1.3×10^{-12} impacts/km^2/yr for craters larger than 1 km (0.6 mi). It is commonly assumed that meteorite impacts are randomly distributed across the earth's surface, although Halliday (1964, pp. 267-277) calculated that the rate of impact in polar regions would be some 50 to 60 percent of that in equatorial regions. The frequencies reported by Grieve (Grieve 1987) would correspond to an overall rate of about 1 per 1,000 yrs on the basis of a random distribution.

Assuming the higher estimated impact rate of 17×10^{-13} impacts per square kilometer per yr for impacts leading to fracturing of sufficient extent to affect a deep repository, and assuming a repository footprint of 1.4 km × 1.6 km (0.9 mi × 1.0 mi) for the WIPP, yields a frequency of about 4×10^{-12} impacts per yr for a direct hit above the repository. This impact frequency is several orders of magnitude below the screening threshold of 10^{-4} per 10,000 yrs provided in section 194.32(d).

Meteorite hits directly above the repository footprint are not the only impacts of concern, however, because large craters may disrupt the waste panels even if the center of the crater is outside the repository area. It is possible to calculate the frequency of meteorite impacts that could disrupt a deep repository such as the WIPP by using the conservative model of a cylinder of rock fractured to a depth equal to one-half the crater diameter, as shown in the CCA, Appendix SCR, Figure SCR-1. The area within which a meteorite could impact the repository is calculated by

$$S_D = \left(L + 2 \times \frac{D}{2} \right) \times \left(W + 2 \times \frac{D}{2} \right), \qquad \text{(SCR.1)}$$

where

L = length of the repository footprint (km)

W = width of the repository footprint (km)
D = diameter of the impact crater (km)
S_D = area of the region where the crater would disrupt the repository (km^2)

There are insufficient data on meteorites that have struck the earth to derive a distribution function for the size of craters directly. Using meteorite impacts on the moon as an analogy, however, Grieve (Grieve 1987, p. 257) derived the following distribution function:

$$F_D \propto D^{-1.8} \qquad \text{(SCR.2)}$$

where

F_D = frequency of impacts resulting in craters larger than D (impacts/km^2/yr).

If $f(D)$ denotes the frequency of impacts giving craters of diameter D, then the frequency of impacts giving craters larger than D is

$$F_D = \int_D^\infty f(D)\, dD \qquad \text{(SCR.3)}$$

and

$$f\left(D\right)=F_1\times1.8\times D^{-2.8}, \quad \text{(SCR.4)}$$

where

F_1 = frequency of impacts resulting in craters larger than 1 km (impacts/km^2/yr)

$f(D)$ = frequency of impacts resulting in craters of diameter D ((impacts/km^2/yr)

The overall frequency of meteorite impacts, in the size range of interest, that could disrupt or fracture the repository is thus given by

$$N=\int_{2h}^{M} f\left(D\right)\times S_D dD, \quad \text{(SCR.5)}$$

where

h = depth to repository (kilometers),

M = maximum size of meteorite considered (kilometers)
N = frequency of impacts leading to disruption of the repository (impacts per yr), and

$$N=1.8F_1\left[\frac{(M)^{0.2}-(2h)^{0.2}}{0.2}-LW\frac{(M)^{-1.8}-(2h)^{-1.8}}{1.8}-(L+W)\frac{(M)^{-0.8}-(2h)^{-0.8}}{0.8}\right]. \quad \text{(SCR.6)}$$

Conservatively using the size (933 km [550 mi]) of the largest known asteroid, Ceres (Tedesco 1992), for the maximum size considered and if it is assumed that the repository is located at a depth of 650 m (2,150 ft) and has a footprint area of 1.4 km × 1.6 km (0.9 mi × 1.0 mi) and that meteorites creating craters larger than 1 km in diameter hit the earth at a frequency (F_1) of 17 × 10^{-13} impacts/km^2/yr, then Equation (SCR.6) gives a frequency of approximately 5.6 × 10^{-11} impacts per yr for impacts disrupting the repository. If impacts are randomly distributed over time, this corresponds to a probability of 5.6 × 10^{-7} over 10,000 yrs.

Similar calculations have been performed that indicate rates of impact of between 10^{-12} and 10^{-13} per yr for meteorites large enough to disrupt a deep repository (see, for example, Hartmann 1979, Kärnbränslesakerhet 1978, Claiborne and Gera 1974, Cranwell et al. 1990, and Thorne 1992). Meteorite impact can thus be eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

Assuming a random or nearly random distribution of meteorite impacts, cratering at any location is inevitable given sufficient time. Although repository depth and host-rock lithology may reduce the consequences of a meteorite impact, there are no repository locations or engineered systems that can reduce the probability of impact over 10,000 yrs.

SCR-4.4.1.5 **FEP Number:** N41 and N42

FEP Titles: *Mechanical Weathering* (N41)
Chemical Weathering (N42)

SCR-4.4.1.5.1 Screening Decision: SO-C

The effects of *Chemical Weathering* and *Mechanical Weathering* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4.1.5.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.4.1.5.3 Screening Argument

Mechanical weathering and chemical weathering are assumed to be occurring at or near the surface around the WIPP site through processes such as exfoliation and leaching. The extent of these processes is limited and they will contribute little to the overall rate of erosion in the area or to the availability of material for other erosional processes. The effects of chemical weathering and mechanical weathering have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4.1.6 **FEP Numbers:** N43, N44, and N45

FEP Titles: *Aeolian Erosion* (N43)
Fluvial Erosion (N44)
Mass Wasting (N45)

SCR-4.4.1.6.1 Screening Decision: SO-C

The effects of *Fluvial Erosion*, *Aeolian Erosion*, and *Mass Wasting* in the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4.1.6.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-4.4.1.6.3 Screening Argument

The geomorphological regime on the Mescalero Plain (Los Medaños) in the region of the WIPP is dominated by aeolian processes. Dunes are present in the area, and although some are stabilized by vegetation, aeolian erosion will occur as they migrate across the area. Old dunes will be replaced by new dunes, and no significant changes in the overall thickness of aeolian material are likely to occur.

Currently, precipitation in the region of the WIPP is too low (about 33 centimeters [cm] [13 inches (in.)] per yr) to cause perennial streams, and the relief in the area is too low for extensive sheet flood erosion during storms. An increase in precipitation to around 61 cm (24 in.) per yr in cooler climatic conditions could result in perennial streams, but the nature of the relief and the presence of dissolution hollows and sinks will ensure that these streams remain small. Significant fluvial erosion is not expected during the next 10,000 yrs.

Mass wasting (the downslope movement of material caused by the direct effect of gravity) is important only in terms of sediment erosion in regions of steep slopes. In the vicinity of the WIPP, mass wasting will be insignificant under the climatic conditions expected over the next 10,000 yrs.

Erosion from wind, water, and mass wasting will continue in the WIPP region throughout the next 10,000 yrs at rates similar to those occurring at present. These rates are too low to affect the performance of the disposal system significantly. Thus, the effects of fluvial erosion, aeolian erosion, and mass wasting have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4.1.7 FEP Number: N50
FEP Title: *Soil Development*

SCR-4.4.1.7.1 Screening Decision: SO-C

Soil Development has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.4.1.7.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.4.1.7.3 Screening Argument

The Mescalero caliche is a well-developed calcareous remnant of an extensive soil profile across the WIPP site and adjacent areas. Although this unit may be up to 3 m (10 ft) thick, it is not continuous and does not prevent infiltration to the underlying formations. At Nash Draw, this caliche, dated in Lappin et al. (Lappin et al. 1989, pp. 2-4) at 410,000 to 510,000 yrs old, is present in collapse blocks, indicating some growth of Nash Draw in the late Pleistocene. Localized gypsite spring deposits about 25,000 yrs old occur along the eastern flank of Nash Draw, but the springs are not currently active. The Berino soil, interpreted as 333,000 yrs old (Rosholt and McKinney 1980, Table 5), is a thin soil horizon above the Mescalero caliche. The persistence of these soils on the Livingston Ridge and the lack of deformation indicates the relative stability of the WIPP region over the past half-million yrs.

Continued growth of caliche may occur in the future but will be of low consequence in terms of its effect on infiltration. Other soils in the area are not extensive enough to affect the amount of infiltration that reaches underlying aquifers. Soil development has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5 Surface Hydrological FEPs

SCR-4.5.1 Depositional Processes

SCR-4.5.1.1	**FEP Numbers:**	N46, N47, N48, and N49
	FEP Titles:	*Aeolian Deposition* (N46) *Fluvial Deposition* (47) *Lacustrine Deposition* (N48) *Mass Waste (Deposition)* (N49)

SCR-4.5.1.1.1 Screening Decision: SO-C

The effects of *Aeolian Deposition*, *Fluvial Deposition*, and *Lacustrine Deposition* and sedimentation in the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.1.1.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.5.1.1.3 Screening Argument

The geomorphological regime on the Mescalero Plain (Los Medaños) in the region of the WIPP is dominated by aeolian processes, but although some dunes are stabilized by vegetation, no significant changes in the overall thickness of aeolian material are expected to occur. Vegetational changes during periods of wetter climate may further stabilize the dune fields, but aeolian deposition is not expected to significantly increase the overall thickness of the superficial deposits.

The limited extent of water courses in the region of the WIPP, under both present-day conditions and under the expected climatic conditions, will restrict the amount of fluvial deposition and lacustrine deposition in the region.

Mass wasting (deposition) may be significant if it results in dams or modifies streams. In the region around the WIPP, the Pecos River forms a significant water course some 19 km (12 mi) away, but the broadness of its valley precludes either significant mass wasting or the formation of large impoundments.

Sedimentation from wind, water, and mass wasting is expected to continue in the WIPP region throughout the next 10,000 yrs at the low rates similar to those occurring at present. These rates are too low to significantly affect the performance of the disposal system. Thus, the effects of aeolian deposition, fluvial deposition, and lacustrine deposition and sedimentation resulting from mass wasting have been eliminated from PA calculations on the basis of low consequence.

SCR-4.5.2 Streams and Lakes

SCR-4.5.2.1 FEPs Number: N51

FEPs Title: *Stream and River Flow*

SCR-4.5.2.1.1 Screening Decision: SO-C

Stream and River Flow has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.5.2.1.3 Screening Argument

No perennial streams are present at the WIPP site, and there is no evidence in the literature indicating that such features existed at this location since the Pleistocene (see, for example, Powers et al. 1978; Bachman 1974, Bachman 1981, and Bachman 1987b). The Pecos River is approximately 19 km (12 mi) from the WIPP site and more than 90 m (300 ft) lower in elevation. Stream and river flow has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.2.2 FEP Number: N52

FEP Title: *Surface Water Bodies*

SCR-4.5.2.2.1 Screening Decision: SO-C

The effects of *Surface Water Bodies* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.5.2.2.3 Screening Argument

No standing surface water bodies are present at the WIPP site, and there is no evidence in the literature indicating that such features existed at this location during or after the Pleistocene (see, for example, Powers et al. 1978, and Bachman 1974, Bachman 1981, and Bachman 1987b). In Nash Draw, lakes and spoil ponds associated with potash mines are located at elevations 30 m (100 ft) below the elevation of the land surface at the location of the waste panels. There is no evidence in the literature to suggest that Nash Draw was formed by stream erosion or was at any time the location of a deep body of standing water, although shallow playa lakes have existed there at various times. Based on these factors, the formation of large lakes is unlikely and the formation of smaller lakes and ponds is of little consequence to the performance of the disposal system. The effects of surface water bodies have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.3 Groundwater Recharge and Discharge

SCR-4.5.3.1

FEP Numbers: N53, N54, and N55
FEP Titles: *Groundwater Discharge* (N53)
Groundwater Recharge (N54)
Infiltration (N55)

SCR-4.5.3.1.1 Screening Decision: UP

Groundwater Recharge, Groundwater Discharge, and Infiltration are accounted for in PA calculations.

SCR-4.5.3.1.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.5.3.1.3 Screening Argument

The groundwater basin described in the CCA, Chapter 2.0, Section 2.2.1.4 is governed by flow from areas where the water table is high to areas where the water table is low. The height of the water table is governed by the amount of groundwater recharge reaching the water table, which in turn is a function of the vertical hydraulic conductivity and the partitioning of precipitation between evapotranspiration, runoff, and infiltration. Flow within the Rustler is also governed by the amount of groundwater discharge that takes place from the basin. In the region around the WIPP, the principal discharge areas are along Nash Draw and the Pecos River. Groundwater flow modeling accounts for infiltration, recharge, and discharge (the CCA, Chapter 2.0, Section 2.2.1.4 and Chapter 6.0, Section 6.4.10.2).

SCR-4.5.3.2

FEP Number: N56
FEP Title: *Changes in Groundwater Recharge and Discharge*

SCR-4.5.3.2.1 Screening Decision: UP

Changes in Groundwater Recharge and Discharge arising as a result of climate change are accounted for in PA calculations.

SCR-4.5.3.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.5.3.2.3 Screening Argument

Changes in recharge may affect groundwater flow and radionuclide transport in units such as the Culebra and Magenta dolomites. Changes in the surface environment driven by natural climate change are expected to occur over the next 10,000 yrs (see FEPs N59 to N63). Groundwater basin modeling (the CCA, Chapter 2.0, Section 2.2.1.4) indicates that a change in recharge will affect the height of the water table in the area of the WIPP, and that this will in turn affect the direction and rate of groundwater flow.

The present-day water table in the vicinity of the WIPP is within the Dewey Lake at about 980 m (3,215 ft) above mean sea level (the CCA, Chapter 2.0, Section 2.2.1.4.2.1). An increase in recharge relative to present-day conditions would raise the water table, potentially as far as the local ground surface. Similarly, a decrease in recharge could result in a lowering of the water table. The low transmissivity of the Dewey Lake and the Rustler ensures that any such lowering of the water table will be at a slow rate, and lateral discharge from the groundwater basin is expected to persist for several thousand yrs after any decrease in recharge. Under the anticipated changes in climate over the next 10,000 yrs, the water table will not fall below the base of the Dewey Lake, and dewatering of the Culebra is not expected to occur during this period (the CCA, Chapter 2.0, Section 2.2.1.4).

Changes in groundwater recharge and discharge are accounted for in PA calculations through definition of the boundary conditions for flow and transport in the Culebra (the CCA, Chapter 6.0, Section 6.4.9, and Appendix PA-2014, Section PA-4.8.3).

SCR-4.5.3.3 **FEP Numbers:** N57 and N58

FEP Titles: *Lake Formation* (N57)
River Flooding (N58)

SCR-4.5.3.3.1 Screening Decision: SO-C

The effects of *River Flooding* and *Lake Formation* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.5.3.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.5.3.3.3 Screening Argument

Intermittent flooding of stream channels and the formation of shallow lakes will occur in the WIPP region over the next 10,000 yrs. These may have a short-lived and local effect on the height of the water table, but are unlikely to affect groundwater flow in the Culebra.

Future occurrences of playa lakes or other longer-term floods will be remote from the WIPP and will have little consequence on system performance in terms of groundwater flow at the site. There is no reason to believe that any impoundments or lakes could form over the WIPP site itself. Thus, river flooding and lake formation have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.6 Climate EPs

SCR-4.6.1 Climate and Climate Changes

SCR-4.6.1.1	**FEP Numbers:**	N59 and N60
	FEP Titles:	*Precipitation* (N59) *Temperature* (N60)

SCR-4.6.1.1.1 Screening Decision: UP

Precipitation and Temperature are accounted for in PA calculations.

SCR-4.6.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.6.1.1.3 Screening Argument

The climate and meteorology of the region around the WIPP are described in the CCA, Section 2.5.2. Precipitation in the region is low (about 33 cm [13 in.] per yr) and temperatures are moderate with a mean annual temperature of about 63 °F (17 °C). Precipitation and temperature are important controls on the amount of recharge that reaches the groundwater system and are accounted for in PA calculations by use of a sampled parameter for scaling flow velocity in the Culebra (see Appendix PA-2014, Section PA-4.8).

SCR-4.6.1.2	**FEP Number:**	N61
	FEP Title:	*Climate Change*

SCR-4.6.1.2.1 Screening Decision: UP

Climate Change is accounted for in PA calculations.

SCR-4.6.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.6.1.2.3 Screening Argument

Climate changes are instigated by changes in the earth's orbit and by feedback mechanisms within the atmosphere and hydrosphere. Models of these mechanisms, combined with interpretations of the geological record, suggest that the climate will become cooler and wetter in the WIPP region during the next 10,000 yrs as a result of natural causes. Other changes, such as fluctuations in radiation intensity from the sun and variability within the many feedback mechanisms, will modify this climatic response to orbital changes. The available evidence suggests that these changes will be less extreme than those arising from orbital fluctuations.

The effect of a change to cooler and wetter conditions is considered to be an increase in the amount of recharge, which in turn will affect the height of the water table (see FEPs N53 through N56, Section SCR-4.5.3.1 and SCR-4.5.3.2). The height of the water table across the groundwater basin is an important control on the rate and direction of groundwater flow within the Culebra (see the CCA, Chapter 2.0, Section 2.2.1.4), and hence potentially on transport of radionuclides released to the Culebra through the shafts or intrusion boreholes. Climate change is accounted for in PA calculations through a sampled parameter used to scale groundwater flow velocity in the Culebra (see Appendix PA-2014, Section PA-4.8).

SCR-4.6.1.3 **FEP Numbers:** N62 and N63
FEP Titles: *Glaciation* (N62)
Permafrost (N63)

SCR-4.6.1.3.1 Screening Decision: SO-P

Glaciation and the effects of *Permafrost* have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-4.6.1.3.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.6.1.3.3 Screening Argument

No evidence exists to suggest that the northern part of the Delaware Basin has been covered by continental glaciers at any time since the beginning of the Paleozoic Era. During the maximum extent of continental glaciation in the Pleistocene Epoch, glaciers extended into northeastern Kansas at their closest approach to southeastern New Mexico. There is no evidence that alpine glaciers formed in the region of the WIPP during the Pleistocene glacial periods.

According to the theory that relates the periodicity of climate change to perturbations in the earth's orbit, a return to a full glacial cycle within the next 10,000 yrs is highly unlikely (Imbrie and Imbrie 1980, p. 951).

Thus, glaciation has been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs. Similarly, a number of processes associated with the proximity of an ice sheet or valley glacier, such as permafrost and accelerated slope erosion (solifluction) have been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 yrs.

SCR-4.7 Marine FEPs

SCR-4.7.1 Seas, Sedimentation, and Level Changes

SCR-4.7.1.1

FEP Numbers: N64 and N65
FEP Titles: *Seas and Oceans* (N64)
Estuaries (N65)

SCR-4.7.1.1.1 Screening Decision: SO-C

The effects of *Estuaries* and *Seas and Oceans* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.7.1.1.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.7.1.1.3 Screening Argument

The WIPP site is more than 800 km (480 mi) from the Pacific Ocean and from the Gulf of Mexico. Estuaries and seas and oceans have therefore been eliminated from PA calculations on the basis of low consequence to the disposal system.

SCR-4.7.1.2

FEPs Numbers: N66 and N67
FEPs Titles: *Coastal Erosion* (N66)
Marine Sediment Transport and Deposition (N67)

SCR-4.7.1.2.1 Screening Decision: SO-C

Coastal Erosion and *Marine Sediment Transport and Deposition* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.7.1.2.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-4.7.1.2.3 Screening Argument

The WIPP site is more than 800 km (480 mi) from the Pacific Ocean and Gulf of Mexico. The effects of coastal erosion and marine sediment transport and deposition have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.7.1.3 **FEP Number:** N68

FEP Title: *Sea Level Changes*

SCR-4.7.1.3.1 Screening Decision: SO-C

The effects of both short-term and long-term *Sea Level Changes* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.7.1.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.7.1.3.3 Screening Argument

The WIPP site is some 1,036 m (3,400 ft) above sea level. Global sea level changes may result in sea levels as much as 140 m (460 ft) below that of the present day during glacial periods, according to Chappell and Shackleton (Chappell and Shackleton 1986, p. 138). This can have marked effects on coastal aquifers. During the next 10,000 yrs, the global sea level can be expected to drop towards this glacial minimum, but this will not affect the groundwater system in the vicinity of the WIPP. Short-term changes in sea level, brought about by events such as meteorite impact, tsunamis, seiches, and hurricanes may raise water levels by several tens of meters. Such events have a maximum duration of a few days and will have no effect on the surface or groundwater systems at the WIPP site. Anthropogenic-induced global warming has been conjectured by Warrick and Oerlemans (Warrick and Oerlemans 1990, p. 278) to result in longer-term sea level rise. The magnitude of this rise, however, is not expected to be more than a few meters, and such a variation will have no effect on the groundwater system in the WIPP region. Thus, the effects of both short-term and long-term sea level changes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.8 Ecological FEPs

SCR-4.8.1 Flora and Fauna

SCR-4.8.1.1 **FEP Numbers:** N69 and N70

FEP Titles: *Plants* (N69)
Animals (N70)

SCR-4.8.1.1.1 Screening Decision: SO-C

The effects of the natural *Plants* and *Animals* (flora and fauna) in the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.8.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.8.1.1.3 Screening Argument

The terrestrial and aquatic ecology of the region around the WIPP is described in the CCA, Chapter 2.0, Section 2.4.1. The plants in the region are predominantly shrubs and grasses. The most conspicuous animals in the area are jackrabbits and cottontail rabbits. The effects of this flora and fauna in the region have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.8.1.2 FEP Number: N71
FEP Title: *Microbes*

SCR-4.8.1.2.1 Screening Decision: SO-C (UP for colloidal effects and gas generation)

The effects of *Microbes* on the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.8.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.8.1.2.3 Screening Argument

Microbes are presumed to be present within the thin soil horizons and in groundwater (Gillow et al. 2000; Swanson and Simmons 2013; Appendix SOTERM-2014, Section 2.4.1). The adsorption of actinides, or their analogs, onto microbial surfaces is dependent upon many factors, including biomass concentration, organism type, actinide oxidation state, the presence of complexing agents, matrix ionic strength and pH. These factors, for the key An(III) and An(IV) oxidation states, were accounted for under WIPP-relevant conditions (Reed et al. 2013; Appendix SOTERM-2014, Section 3.9). These biocolloids are relatively large in size (>0.3 μ) and exhibit relatively low sorption when compared to the inorganic and organic complexants also present. The density of microbial cells as colloidal particles will be limited by their low relative sorption and will be rapidly reduced by filtration in the Culebra because of their relative large size, leading to the conclusion that microbial colloids will have an insignificant impact on radionuclide transport in the Culebra. A similar conclusion is also observed in other deep geologic disposal concepts (e.g., for the Swedish granite concept (Pederson 1999)).

SCR-4.8.1.3 **FEP Number:** N72
FEP Title: *Natural Ecological Development*

SCR-4.8.1.3.1 Screening Decision: SO-C

The effects of *Natural Ecological Development* likely to occur in the region of the WIPP have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-4.8.1.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-4.8.1.3.3 Screening Argument

The region around the WIPP is sparsely vegetated as a result of the climate and poor soil quality. Wetter periods are expected during the regulatory period, but botanical records indicate that, even under these conditions, dense vegetation will not be present in the region (Swift 1992; see the CCA, Appendix CLI, p. 17). The effects of the indigenous fauna are of low consequence to the performance of the disposal system and no natural events or processes have been identified that would lead to a change in this fauna that would be of consequence to system performance. Natural ecological development in the region of the WIPP has therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.0 Screening of Human-Induced EPs

The following section presents screening arguments and decisions for human-induced EPs. Table SCR-1 provides summary information regarding changes to human-induced EPs since the CCA. Of the 61 human-induced EPs included in the CRA-2014, 52 remain unchanged, and 9 were updated with new information.

SCR-5.1 Human-Induced Geological EPs

SCR-5.1.1 Drilling

SCR-5.1.1.1	**FEP Numbers:**	H1, H2, H4, H8, and H9
	FEP Titles:	*Oil and Gas Exploration* (H1) *Potash Exploration* (H2) *Oil and Gas Exploitation* (H4) *Other Resources (drilling for)* (H8) *Enhanced Oil and Gas Recovery* (drilling for) (H9)

SCR-5.1.1.1.1 Screening Decision: SO-C (HCN)
DP (Future)

The effects of historical, current, and near-future drilling associated with Oil and Gas Exploration, Potash Exploration, Oil and Gas Exploitation, Drilling for Other Resources, and Drilling for Enhanced Oil and Gas Recovery has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system (see screening discussion for H21, H22, and H23). Oil and gas exploration, potash exploration, oil and gas exploitation, drilling for other resources, and enhanced oil and gas recovery in the future is accounted for in DP scenarios through incorporation of the rate of future drilling as specified in section 194.33.

SCR-5.1.1.1.2 Summary of New Information

The CRA-2014 will use an updated drilling rate as required by section 194.33. This new rate does not change the screening argument or decision for FEPs H1, Oil and Gas Exploration, H4, Oil and Gas Exploitation, H8, Other Resources, and H9, Enhanced Oil and Gas Recovery. This updated deep drilling rate is implemented through the PA parameter GLOBAL:LAMBDAD. For the CRA-2014, the value for this parameter is 6.73×10^{-3} boreholes per km^2 per yr. This is an increase to the value of 5.98×10^{-3} boreholes per km^2 per yr used in the CRA-2009 PABC. Additionally, further exploitation of the existing oil leases in Section 31 (beneath the southeast corner of the WIPP site) has occurred via horizontal drilling.

SCR-5.1.1.1.3 Historical, Current, and Near-Future Human EPs

Resource exploration and exploitation are the most common reasons for drilling in the Delaware Basin and are the most likely reasons for drilling in the near future. The WIPP location has been evaluated for the occurrence of natural resources in economic quantities. Powers et al. (Powers et al. 1978) (the CCA, Appendix GCR, Chapter 8) investigated the potential for exploitation of potash, hydrocarbons, caliche, gypsum, salt, uranium, sulfur, and lithium. Also, in 1995, the New Mexico Bureau of Mines and Mineral Resources performed a reevaluation of the mineral resources at and within 1.6 km (1 mi) around the WIPP site (New Mexico Bureau of Mines and Mineral Resources 1995). While some resources do exist at the WIPP site, for the HCN time frames, such drilling is assumed to only occur outside the WIPP site boundary, with the exception of horizontal wells beneath Section 31 (the southwest corner of the WIPP site). Oil leases that pre-existed the withdrawal of land by the Federal government for the WIPP in Section 31 were not condemned, as it was determined that production of these resources could be conducted without adverse effects to the WIPP. As such, the DOE only controls from the surface to 6,000 ft (1,829 m) below ground surface. Operators have continued to produce these leases and four new horizontal wells have been drilled beneath this section since the last recertification application. This continued development and production is consistent with the expectations of the DOE and the EPA (U.S. EPA 1998c). These wells originate outside the WIPP boundary and transition to horizontal orientation at depths below 6,000 ft (1,829 m). The vertical portion of these drill holes lie outside the WIPP boundary. Therefore, it is not expected that vertical wells will be initiated within the WIPP site during the HCN time frame. This assumption is based on current federal ownership and management of the WIPP during operations, and assumed effectiveness of institutional controls for the 100-yr period immediately following site closure.

Drilling associated with oil and gas exploration and oil and gas exploitation currently takes place in the vicinity of the WIPP. For example, gas is extracted from reservoirs in the Morrow Formation, some 4,200 m (14,000 ft) below the surface, and oil is extracted from shallower units within the Delaware Mountain Group, some 2,150 to 2,450 m (7,000 to 8,000 ft) below the surface.

Potash resources in the vicinity of the WIPP are discussed in the CCA, Chapter 2.0, Section 2.3.1.1. Throughout the Carlsbad Potash District, commercial quantities of potash are restricted to the McNutt, which forms part of the Salado above the repository horizon. Potash exploration and evaluation boreholes have been drilled within and outside the controlled area. Such drilling will continue outside the WIPP land withdrawal boundary, but no longer occurs within the boundary because rights and controls have been transferred to the DOE. Moreover, drilling for the evaluation of potash resources within the boundary will not occur throughout the time period of active institutional controls (AICs).

Drilling for other resources has taken place within the Delaware Basin. For example, sulfur extraction using the Frasch process began in 1969 and continued for three decades at the Culberson County Rustler Springs mine near Orla, Texas. In addition, brine wells have been in operation in and about the Delaware Basin for at least as long. Solution mining processes for sulfur, salt (brine), potash, or any other mineral are not addressed in this FEP; only the drilling of the borehole is addressed here. Resource extraction through solution mining and any potential effects are evaluated in Section SCR-5.2.2.3 (*Solution Mining for Potash* [H58]). Nonetheless, the drilling activity associated with the production of other resources is not notably different than drilling for petroleum exploration and exploitation.

Drilling for the purposes of reservoir stimulation and subsequent enhanced oil and gas recovery does take place within the Delaware Basin, although systematic, planned waterflooding has not taken place near the WIPP. Instead, injection near the WIPP consists of single-point injectors, rather than broad, grid-type waterflood projects (Hall et al. 2013). In the vicinity of the WIPP, fluid injection usually takes place using boreholes initially drilled as producing wells. Therefore, regardless of the initial intent of a deep borehole, whether in search of petroleum reserves or as an injection point, the drilling event and associated processes are virtually the same. These drilling-related processes are addressed more fully in Section SCR-5.2.1.1 (*Drilling Fluid Flow* [H21]), Section SCR-5.2.1.2 (*Drilling Fluid Loss* [H22]), and Section SCR-5.2.1.3 (*Blowouts* [H23]). Discussion on the effects subsequent to drilling a borehole for the purpose of enhancing oil and gas recovery is discussed in Section SCR-5.2.1.6 *(Enhanced Oil and Gas Production [H28])*.

In summary, drilling associated with oil and gas exploration, potash exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling associated with Other Resources has taken place and is expected to continue in the Delaware Basin. The potential effects of existing and possible near-future boreholes on fluid flow and radionuclide transport within the disposal system are discussed in FEPs H25 through H36 (Section SCR-5.2.1.5, Section SCR-5.2.1.6, Section SCR-5.2.1.7, Section SCR-5.2.1.8, Section SCR-5.2.1.9, Section SCR-5.2.1.10, Section SCR-5.2.1.11, Section SCR-5.2.1.12, and Section SCR-5.2.1.13), where low-consequence screening arguments are provided.

SCR-5.1.1.1.4 Future Human EPs

Criteria in section 194.33 require the DOE to examine the historical rate of drilling for resources in the Delaware Basin. Thus, consistent with section 194.33(b)(3)(i), the DOE has used the historical record of deep drilling associated with oil and gas exploration, potash exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling associated with other resources (sulfur exploration) in the Delaware Basin in calculations to determine the rate of future deep drilling in the Delaware Basin (see Section 33 of this application).

SCR-5.1.1.2

FEP Numbers: H3 and H5
FEP Titles: *Water Resources Exploration* (H3)
Groundwater Exploitation (H5)

SCR-5.1.1.2.1 Screening Decision: SO-C (HCN)
SO-C (Future)

The effects of HCN and future drilling associated with *Water Resources Exploration* and *Groundwater Exploitation* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Historical shallow drilling associated with *Water Resources Exploration* and *Groundwater Exploitation* is accounted for in calculations to determine the rate of future shallow drilling.

SCR-5.1.1.2.2 Summary of New Information

The Delaware Basin Monitoring Program records and tracks the development of deep and shallow wells within the vicinity of the WIPP. An updated shallow drilling rate of 2.88×10^{-3} boreholes per km^2 per yr was calculated in the Delaware Basin Monitoring Annual Report (U.S. DOE 2012). While this information has been updated since the last recertification, it does not result in a change in the screening arguments or decisions of these FEPs.

SCR-5.1.1.2.3 Screening Argument

Drilling associated with water resources exploration and groundwater exploitation has taken place and is expected to continue in the Delaware Basin. For the most part, water resources in the vicinity of the WIPP are scarce. Elsewhere in the Delaware Basin, potable water occurs in places while some communities rely solely on groundwater sources for drinking water. Even though water resources exploration and groundwater exploitation occur in the Basin, all such exploration/exploitation is confined to shallow drilling that extends no deeper than the Rustler. Thus, it will not impact repository performance because of the limited drilling anticipated in the future and the sizeable thickness of low-permeability Salado salt between the waste panels and the shallow groundwaters. Given the limited groundwater resources and minimal consequence of shallow drilling on performance, the effects of HCN and future drilling associated with water resources exploration and groundwater exploitation have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The screening argument therefore remains the same as given previously in the CCA.

Although shallow drilling for water resources exploration and groundwater exploitation have been eliminated from PA calculations, the DBDSP continues to collect drilling data related to water resources, as well as other shallow drilling activities. As shown in the DBDSP 2012 Annual Report (U.S. DOE 2012), the total number of shallow water wells in the Delaware Basin is currently 2,296, compared to 2,331 shallow water wells reported in the CCA. This decrease of 35 wells is attributed primarily to the reclassification of water wells to other types of shallow boreholes. Based on these data, the shallow drilling rate for water resources exploration and groundwater exploitation is essentially the same as reported in the CCA. The distribution of groundwater wells in the Delaware Basin was included in the CCA, Appendix USDW, Section USDW.3.

SCR-5.1.1.2.4 Historical, Current, and Near-Future Human EPs

Water is currently extracted from formations above the Salado, as discussed in the CCA, Chapter 2.0, Section 2.3.1.3. The distribution of groundwater wells in the Delaware Basin is included in the CCA, Appendix USDW, Section USDW.3. Water resources exploration and groundwater exploitation are expected to continue in the Delaware Basin.

In summary, drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling to explore other resources has taken place and is expected to continue in the Delaware Basin. The potential effects of existing and possible near-future boreholes on fluid flow and radionuclide transport within the disposal system are discussed in Section SCR-5.2, where low-consequence screening arguments are provided.

SCR-5.1.1.2.5 Future Human EPs

Criteria in section 194.33 require that, to calculate the rates of future shallow and deep drilling in the Delaware Basin, the DOE should examine the historical rate of drilling for resources in the Delaware Basin.

Shallow drilling associated with water, potash, sulfur, oil, and gas extraction has taken place in the Delaware Basin over the past 100 yrs. However, of these resources, only water and potash are present at shallow depths (less than 655 m (2,150 ft) below the surface) within the controlled area. Thus, consistent with section 194.33(b)(4), the DOE includes drilling associated with water resources exploration, potash exploration, and groundwater exploitation in calculations to determine the rate of future shallow drilling in the Delaware Basin. However, the effects of such events are not included in PA calculations because of low consequence to the performance of the disposal system.

SCR-5.1.1.3

FEP Numbers: H6, H7, H10, H11, and H12
FEP Titles: *Archeological Investigations* (H6)
Geothermal Energy Production (H7)
Liquid Waste Disposal (H10)
Hydrocarbon Storage (H11)
Deliberate Drilling Intrusion (H12)

SCR-5.1.1.3.1 Screening Decision: SO-R (HCN)
SO-R (Future)

Drilling associated with Archeological Investigations, Geothermal Energy Production, Liquid Waste Disposal, Hydrocarbon Storage, and Deliberate Drilling Intrusion have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.1.3.2 Summary of New Information

No new information that affects the screening of these FEPs has been identified since the CRA-2009.

SCR-5.1.1.3.3 Screening Argument

SCR-5.1.1.3.3.1 Historic, Current, and Near-Future EPs

No drilling associated with archeology or geothermal energy production has taken place in the Delaware Basin. Consistent with the future states assumptions in section 194.25(a) (U.S. EPA 1996), such drilling activities have been eliminated from PA calculations on regulatory grounds.

While numerous archeological sites exist at and near the WIPP site, drilling for archeological purposes has not occurred. Archeological investigations have only involved shallow surface disruptions, and do not require deeper investigation by any method, drilling or otherwise. Geothermal energy is not considered to be a potentially exploitable resource because economically attractive geothermal conditions do not exist in the northern Delaware Basin.

Oil and gas production byproducts are disposed of underground in the WIPP region, but such liquid waste disposal does not involve drilling of additional boreholes (see H27, Section SCR-5.2.1.6); therefore drilling of boreholes for the explicit purpose of disposal has not occurred.

Hydrocarbon storage takes place in the Delaware Basin, but it involves gas injection through existing boreholes into depleted reservoirs (see, for example, Burton et al. 1993, pp. 66-67). Therefore, drilling of boreholes for the explicit purpose of hydrocarbon storage has not occurred.

Consistent with section 194.33(b)(1), all near-future Human EPs relating to deliberate drilling intrusion into the WIPP excavation have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.1.3.3.2 Future Human EPs

Consistent with section 194.33 and the future states assumptions in section 194.25(a), drilling for purposes other than resource recovery (such as WIPP site investigation) and drilling activities that have not taken place in the Delaware Basin over the past 100 yrs need not be considered in determining future drilling rates. Thus, drilling associated with archeological investigations, geothermal energy production, liquid waste disposal, hydrocarbon storage, and deliberate drilling intrusion have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2 Excavation Activities

SCR-5.1.2.1 **FEP Number:** H13
FEP Title: *Conventional Underground Potash Mining*

SCR-5.1.2.1.1 Screening Decision: UP (HCN)
DP (Future)

As prescribed by section 194.32(b), the effects of HCN and future *Conventional Underground Potash Mining* are accounted for in PA calculations (see also FEP H37).

SCR-5.1.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.2.1.3 Screening Argument

Potash is the only known economically viable resource in the vicinity of the WIPP that is recovered by underground mining (see the CCA, Chapter 2.0, Section 2.3.1). Potash is mined extensively by conventional techniques in the region east of Carlsbad and up to 2.4 km (1.5 mi) from the boundaries of the controlled area of the WIPP. According to existing plans and leases (see the CCA, Chapter 2.0, Section 2.3.1.1), potash mining is expected to continue in the vicinity of the WIPP in the near future. The DOE assumes that all economically recoverable potash in the vicinity of the disposal system will be extracted in the near future, although there are no economical reserves above the WIPP waste panels (Griswold and Griswold 1999).

In summary, conventional underground potash mining is currently taking place and is expected to continue in the vicinity of the WIPP in the near future. The potential effects of HCN and future conventional underground potash mining are accounted for in PA calculations as prescribed by section 194.32(b), and as further described in the supplementary information to Part 194 Subpart C, "Compliance Certification and Recertification" and in the Compliance Application Guidance (CAG), Subpart C, § 194.32, Scope of Performance Assessments.

SCR-5.1.2.2 FEP Number: H14
FEP Title: *Other Resources (mining for)*

SCR-5.1.2.2.1 Screening Decision: SO-C (HCN)
SO-R (Future)

HCN *Mining for Other Resources* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Mining for Other Resources* has been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.2.2.3 Screening Argument

Potash is the only known economically viable resource in the vicinity of the WIPP that is recovered by underground mining. Potash is mined extensively in the region east of Carlsbad and up to 5 km (3.1 mi) from the boundaries of the controlled area. According to existing plans and leases, potash mining is expected to continue in the vicinity of the WIPP in the near future. The DOE assumes that all economically recoverable potash in the vicinity of the disposal system will be extracted in the near future. Excavation for resources other than potash and archaeological excavations have taken place or are currently taking place in the Delaware Basin. These activities have not altered the geology of the controlled area significantly, and have been eliminated from PA calculations for the HCN timeframe on the basis of low consequence to the performance of the disposal system.

Potash is the only resource that has been identified within the controlled area in a quality similar to that currently mined elsewhere in the Delaware Basin. Future mining for other resources has been eliminated from PA calculations on the regulatory basis of section 194.25(a).

SCR-5.1.2.3 **FEP Numbers:** H15 and H16

FEP Titles: *Tunneling* (H15)
Construction of Underground Facilities (H16)

SCR-5.1.2.3.1 Screening Decision: SO-R (HCN)
SO-R (Future)

Consistent with section 194.33(b)(1), near-future, human-induced EPs relating to *Tunneling* into the WIPP excavation and *Construction of Underground Facilities* have been eliminated from PA calculations on regulatory grounds. Furthermore, consistent with section 194.25(a), future human-induced EPs relating to *Tunneling* into the WIPP excavation and *Construction of Underground Facilities* have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.3.2 Summary

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.2.3.3 Screening Argument

No tunneling or construction of underground facilities (for example, storage, disposal, accommodation [i.e., dwellings]) has taken place in the Delaware Basin. Mining for potash occurs (a form of tunneling), but is addressed specifically in (Section SCR-5.1.2.1 (*Conventional Underground Potash Mining* [H13])). Gas storage does take place in the Delaware Basin, but it involves injection through boreholes into depleted reservoirs, and not excavation (see, for example, Burton et al. 1993, pp. 66–67).

Because tunneling and construction of underground facilities (other than the WIPP) have not taken place in the Delaware Basin, and consistent with the future-states assumptions in section 194.25(a), such excavation activities have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.4 **FEP Number:** H17

FEP Title: *Archeological Excavations*

SCR-5.1.2.4.1 Screening Decision: SO-C (HCN)
SO-R (Future)

HCN *Archaeological Excavations* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Archaeological Excavations* into the disposal system have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.2.4.3 Screening Argument

Archeological excavations have occurred at or near the WIPP, but involved only minor surface disturbances. These archaeological excavations may continue into the foreseeable future as other archeological sites are discovered. These activities have not altered the geology of the controlled area significantly, and have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system for the HCN timeframe.

Also, consistent with section 194.32(a), which limits the scope of consideration of future human actions to mining and drilling, future archaeological excavations have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.5 FEP Number: H18
FEP Title: *Deliberate Mining Intrusion*

SCR-5.1.2.5.1 Screening Decision: SO-R (HCN)
SO-R (Future)

Consistent with section 194.33(b)(1), near-future, human-induced EPs relating to *Deliberate Mining Intrusion* into the WIPP excavation have been eliminated from PA calculations on regulatory grounds. Furthermore, consistent with section 194.33(b)(1), future human-induced EPs relating to *Deliberate Mining Intrusion* into the WIPP excavation have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.5.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.2.5.3 Screening Argument

Consistent with section 194.33(b)(1), all future human-related EPs relating to deliberate mining intrusion into the WIPP excavation have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.3 Subsurface Explosions

SCR-5.1.3.1 FEPs Number: H19
FEP Title: *Explosions for Resource Recovery*

SCR-5.1.3.1.1 Screening Decision: SO-C (HCN)
SO-R (Future)

Historical underground *Explosions for Resource Recovery* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future underground *Explosions for Resource Recovery* have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.3.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.3.1.3 Screening Argument

This section discusses subsurface explosions associated with resource recovery that may result in pathways for fluid flow between hydraulically conductive horizons. The potential effects of explosions on the hydrological characteristics of the disposal system are discussed in Section SCR-5.2.3.1 (*Changes in Groundwater Flow Due to Explosions* [H39]).

SCR-5.1.3.1.4 Historical, Current, and Near-Future Human EPs

Neither small-scale nor regional-scale explosive techniques to enhance the formation of hydraulic conductivity form a part of current mainstream oil- and gas-production technology. Instead, controlled perforating and hydrofracturing are used to improve the performance of oil and gas boreholes in the Delaware Basin. However, small-scale explosions have been used in the past to fracture oil- and natural-gas-bearing units to enhance resource recovery. The size of explosion used to fracture an oil- or gas-bearing unit is limited by the need to contain the damage within the unit being exploited. In the area surrounding the WIPP, the stratigraphic units with oil and gas resources are too deep for explosions to affect the performance of the disposal system. Thus, the effects of explosions for resource recovery have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Potash mining is currently taking place and is expected to continue in the vicinity of the WIPP in the near future. Potash is mined extensively in the region east of Carlsbad and up to 2.4 km (1.3 mi) from the boundaries of the controlled area. In earlier yrs, conventional drill, blast, load, and rail-haulage methods were used. Today, continuous miners similar to those used in coal-mining have been adapted to fit the potash-salt formations. Hence, drilling and blasting technology is not used in the present day potash mines. Thus, the effects of explosions for resource recovery have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Consistent with section 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, future underground explosions for resource recovery have been eliminated from PA calculations on regulatory grounds.

SCR-5.1.3.2 **FEPs Number:** H20
FEP Title: *Underground Nuclear Device Testing*

SCR-5.1.3.2.1 Screening Decision: SO-C (HCN)
SO-R (Future)

Historical *Underground Nuclear Device Testing* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Underground Nuclear Device Testing* has been eliminated from PA calculations on regulatory grounds.

SCR-5.1.3.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.1.3.2.3 Screening Argument

SCR-5.1.3.2.3.1 Historical, Current, and Near-Future Human EPs

The Delaware Basin has been used for an isolated nuclear test. This test, Project Gnome (Rawson et al. 1965), took place in 1961 at a location approximately 13 km (8 mi) southwest of the WIPP waste disposal region. Project Gnome was decommissioned in 1979.

The primary objective of Project Gnome was to study the effects of an underground nuclear explosion in salt. The Gnome experiment involved the detonation of a 3.1 kiloton nuclear device at a depth of 360 m (1,190 ft) in the bedded salt of the Salado. The explosion created an approximately spherical cavity of about 27,000 cubic meters (m^3) (950,000 cubic ft [ft^3]) and caused surface displacements in a radius of 360 m (1,180 ft). No earth tremors perceptible to humans were reported at distances over 40 km (25 mi) from the explosion. A zone of increased permeability was observed to extend at least 46 m (150 ft) laterally from and 105 m (344 ft) above the point of the explosion. The test had no significant effects on the geological characteristics of the WIPP disposal system. Thus, historical underground nuclear device testing has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Due to a moratorium on underground nuclear testing, there are no existing plans for underground nuclear device testing in the vicinity of the WIPP in the near future.

SCR-5.1.3.2.3.2 Future Human EPs

The criterion in section 194.32(a) relating to the scope of PAs limits the consideration of future human actions to mining and drilling. Therefore, future underground nuclear device testing has been eliminated from PA calculations on regulatory grounds.

SCR-5.2 Subsurface Hydrological and Geochemical EPs

SCR-5.2.1 Borehole Fluid Flow

SCR-5.2.1.1 FEP Number: H21
FEP Title: *Drilling Fluid Flow*

SCR-5.2.1.1.1 Screening Decision: SO-C (HCN)
DP (Future)

Drilling Fluid Flow associated with historical, current, near-future, and future boreholes that do not intersect the waste disposal region has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The possibility of a future deep borehole penetrating a waste panel, such that drilling-induced flow results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in PA calculations. The possibility of a deep borehole penetrating both the waste disposal region and a Castile brine reservoir is accounted for in PA calculations.

SCR-5.2.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.1.3 Screening Argument

Borehole circulation fluid could be lost to thief zones encountered during drilling, or fluid could flow from pressurized zones through the borehole to the land surface (blowout) or to a thief zone. Such drilling-related EPs could influence groundwater flow and, potentially, radionuclide transport in the affected units. Future drilling within the controlled area could result in direct releases of radionuclides to the land surface or transport of radionuclides between hydraulically conductive units.

Movement of brine from a pressurized zone through a borehole into potential thief zones such as the Salado interbeds or the Culebra could result in geochemical changes and altered radionuclide migration rates in these units.

SCR-5.2.1.1.3.1 Historical, Current, and Near-Future Human EPs

Drilling fluid flow is a short-term event that can result in the flow of pressurized fluid from one geologic stratum to another. However, long-term flow through abandoned boreholes would have a greater hydrological impact in the Culebra than a short-term event like drilling-induced flow outside the controlled area. Wallace (Wallace 1996a) analyzed the potential effects of flow through abandoned boreholes in the future within the controlled area, and concluded that interconnections between the Culebra and deep units could be eliminated from PA calculations on the basis of low consequence. Thus, the HCN of drilling fluid flow associated with boreholes outside the controlled area has been screened out on the basis of low consequence to the performance of the disposal system.

As discussed in FEPs H25 through H36 (Section SCR-5.2.1.5, Section SCR-5.2.1.6, Section SCR-5.2.1.7, Section SCR-5.2.1.8, Section SCR-5.2.1.9, Section SCR5.2.1.10, Section SCR-5.2.1.11, Section SCR-5.2.1.12, and Section SCR-5.2.1.13), drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling to explore other resources has taken place or is currently taking place outside the controlled area in the Delaware Basin. These drilling activities are expected to continue in the vicinity of the WIPP in the near future.

SCR-5.2.1.1.3.2 Future Human EPs

For the future, drill holes may intersect the waste disposal region and their effects could be more profound. Thus, the possibility of a future borehole penetrating a waste panel, so that drilling fluid flow and, potentially, blowout results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in PA calculations.

The units intersected by the borehole may provide sources for fluid flow (brine, oil, or gas) to the waste panel during drilling. In the vicinity of the WIPP, the Castile that underlies the Salado contains isolated volumes of brine at fluid pressures greater than hydrostatic. A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. The possibility of a deep borehole penetrating both a waste panel and a brine reservoir is accounted for in PA calculations.

Penetration of an underpressurized unit underlying the Salado could result in flow and radionuclide transport from the waste panel to the underlying unit during drilling, although drillers would minimize such fluid loss to a thief zone through the injection of materials to reduce permeability or through the use of casing and cementing. Also, the permeabilities of formations underlying the Salado are less than the permeability of the Culebra (Wallace 1996a). Thus, the consequences associated with radionuclide transport to an underpressurized unit below the waste panels during drilling will be less significant, in terms of disposal system performance, than the consequences associated with radionuclide transport to the land surface or to the Culebra during drilling. Through this comparison, drilling events that result in penetration of underpressurized units below the waste-disposal region have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-5.2.1.2 **FEP Number:** H22
FEP Title: *Drilling Fluid Loss*

SCR-5.2.1.2.1 Screening Decision: SO-C (HCN)
DP (Future)

Drilling Fluid Loss associated with HCN and future boreholes that do not intersect the waste disposal region has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The possibility of a future *Drilling Fluid Loss* into waste panels is accounted for in PA calculations.

SCR-5.2.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.2.3 Screening Argument

Drilling fluid loss is a short-term event that can result in the flow of pressurized fluid from one geologic stratum to another. Large fluid losses would lead a driller to inject materials to reduce permeability, or it would lead to the borehole being cased and cemented to limit the loss of drilling fluid. Assuming such operations are successful, drilling fluid loss in the near future outside the controlled area will not significantly affect the hydrology of the disposal system. Thus, drilling fluid loss associated with historical, current, and near-future boreholes has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

In evaluating the potential consequences of drilling fluid loss to a waste panel in the future, two types of drilling events need to be considered – those that intercept pressurized fluid in underlying formations such as the Castile (defined in the CCA, Chapter 6.0, Section 6.3.2.2 as E1 events), and those that do not (E2 events). A possible hydrological effect would be to make a greater volume of brine available for gas generation processes and thereby increase gas volumes at particular times in the future. For either type of drilling event, on the basis of current drilling practices, the driller is assumed to pass through the repository rapidly. Relatively small amounts of drilling fluid loss might not be noticed and might not give rise to concern. Larger fluid losses would lead to the driller injecting materials to reduce permeability, or to the borehole being cased and cemented, to limit the loss of drilling fluid.

For boreholes that intersect pressurized brine reservoirs, the volume of fluid available to flow up a borehole will be significantly greater than the volume of any drilling fluid that could be lost. This greater volume of brine is accounted for in PA calculations, and is allowed to enter the disposal room (see the CCA, Chapter 6.0, Section 6.4.7). Thus, the effects of drilling fluid loss will be small by comparison to the potential flow of brine from pressurized brine reservoirs. Therefore, the effects of drilling fluid loss for E1 drilling events have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

The consequences of drilling fluid loss into waste panels in the future are accounted for in PA calculations for E2 events.

SCR-5.2.1.2.3.1 Historical, Current, and Near-Future Human EPs

Drilling fluid flow will not affect hydraulic conditions in the disposal system significantly unless there is substantial drilling fluid loss to a thief zone, such as the Culebra. Typically, zones into which significant borehole circulation fluid is lost are isolated through injection of materials to reduce permeability or through casing and cementing programs. Assuming such operations are successful, drilling fluid loss in the near future outside the controlled area will not affect the hydrology of the disposal system significantly and be of no consequence.

SCR-5.2.1.2.3.2 Future Human EPs

The consequences of drilling within the controlled area in the future will primarily depend on the location of the borehole. Potentially, future deep drilling could penetrate the waste disposal region. Hydraulic and geochemical conditions in the waste panel could be affected as a result of drilling fluid loss to the panel.

Penetration of an underpressurized unit underlying the Salado could result in flow and radionuclide transport from the waste panel to the underlying unit during drilling, although drillers would minimize such fluid loss to a thief zone through the injection of materials to reduce permeability or through the use of casing and cementing. Also, the permeabilities of formations underlying the Salado are less than the permeability of the Culebra (Wallace 1996a). Thus, the consequences associated with radionuclide transport to an underpressurized unit below the waste panels during drilling will be less significant, in terms of disposal system performance, than the consequences associated with radionuclide transport to the land surface or to the Culebra during drilling. Through this comparison, drilling events that result in penetration of underpressurized units below the waste-disposal region have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

For boreholes that do not intersect pressurized brine reservoirs (but do penetrate the waste-disposal region), the treatment of the disposal room implicitly accounts for the potential for greater gas generation resulting from drilling fluid loss. Thus, the hydrological effects of drilling fluid loss for E2 drilling events are accounted for in PA calculations within the conceptual model of the disposal room for drilling intrusions.

SCR-5.2.1.3 **FEP Number:** H23
FEP Title: *Blowouts*

SCR-5.2.1.3.1 Screening Decision: SO-C (HCN)
DP (Future)

Blowouts associated with HCN and future boreholes that do not intersect the waste disposal region have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The possibility of a future deep borehole penetrating a waste panel such that drilling-induced flow results in transport of radionuclides to the land surface or to overlying hydraulically conductive units is accounted for in PA calculations. The possibility of a deep borehole penetrating both the waste disposal region and a Castile brine reservoir is accounted for in PA calculations.

SCR-5.2.1.3.2 Summary of New Information

Blowouts are implemented in PA through the parameter GLOBAL:PBRINE, which represents the probability of an inadvertent intrusion borehole encountering pressurized brine beneath the repository. This parameter has been updated based on new data and analysis as reported in Kirchner et al. (Kirchner et al. 2012). This parameter update does not change the screening argument or decision; H23 *Blowouts* continue to be classified as DP for the future timeframe.

SCR-5.2.1.3.3 Screening Argument

Blowouts are short-term events that can result in the flow of pressurized fluid from one geologic stratum to another. For the near future, a blowout may occur in the vicinity of the WIPP but is not likely to affect the disposal system because of the distance from the well to the waste panels, assuming that AICs are in place which restrict borehole installation to outside the WIPP boundary. *Blowouts* associated with HCN and future boreholes that do not intersect the waste disposal region have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. For the future, the drill holes may intersect the waste disposal region and these effects could be more profound. Thus, *blowouts* are included in the assessment of future activities and their consequences are accounted for in PA calculations.

Fluid could flow from pressurized zones through the borehole to the land surface (*blowout*) or to a thief zone. Such drilling-related EPs could influence groundwater flow and, potentially, radionuclide transport in the affected units. Movement of brine from a pressurized zone through a borehole into potential thief zones such as the Salado interbeds or the Culebra could result in geochemical changes and altered radionuclide migration rates in these units.

SCR-5.2.1.3.3.1 Historical, Current, and Near-Future Human EPs

Drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling to explore other resources has taken place or is currently taking place outside the controlled area in the Delaware Basin. These drilling activities are expected to continue in the vicinity of the WIPP in the near future.

Naturally occurring brine and gas pockets have been encountered during drilling in the Delaware Basin. Brine pockets have been intersected in the Castile (as discussed in the CCA, Chapter 2.0, Section 2.2.1.2). Gas blowouts have occurred during drilling in the Salado. Usually, such events result in brief interruptions in drilling while the intersected fluid pocket is allowed to depressurize through flow to the surface (for a period lasting from a few hours to a few days). Drilling then restarts with an increased drilling mud weight. Under these conditions, blowouts in the near future will cause isolated hydraulic disturbances, but will not affect the hydrology of the disposal system significantly.

Potentially, the most significant disturbance to the disposal system could occur if an uncontrolled blowout during drilling resulted in substantial flow through the borehole from a pressurized zone to a thief zone. For example, if a borehole penetrates a brine reservoir in the Castile, brine could flow through the borehole to the Culebra over the long term, and, as a result, could affect hydraulic conditions in the Culebra. The potential effects of such an event can be compared to the effects of long-term fluid flow from deep overpressurized units to the Culebra through abandoned boreholes. Wallace (Wallace 1996a) analyzed the potential effects of flow through abandoned boreholes in the future within the controlled area and concluded that interconnections between the Culebra and deep units could be eliminated from PA calculations on the basis of low consequence. Long-term flow through abandoned boreholes would have a greater hydrological impact in the Culebra than short-term, drilling-induced flow outside the controlled area. Thus, the effects of fluid flow during drilling in the near future have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

In summary, blowouts associated with historical, current, and near-future boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.3.3.2 Future Human EPs—Boreholes that Intersect the Waste Disposal Region

The consequences of drilling within the controlled area in the future will depend primarily on the location of the borehole. Potentially, future deep drilling could penetrate the waste disposal region. If the borehole intersects the waste in the disposal rooms, radionuclides could be transported as a result of drilling fluid flow: releases to the accessible environment may occur as material entrained in the circulating drilling fluid is brought to the surface. Also, during drilling, contaminated brine may flow up the borehole and reach the surface, depending on fluid pressure within the waste disposal panels; blowout conditions could prevail if the waste panel were sufficiently pressurized at the time of intrusion.

SCR-5.2.1.3.3.3 Hydraulic Effects of Drilling-Induced Flow

The possibility of a future borehole penetrating a waste panel, so that drilling fluid flow and, potentially, blowout results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in PA calculations.

The units intersected by the borehole may provide sources for fluid flow (brine, oil, or gas) to the waste panel during drilling. In the vicinity of the WIPP, the Castile that underlies the Salado contains isolated volumes of brine at fluid pressures greater than hydrostatic. A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. The possibility of a deep borehole penetrating both a waste panel and a brine reservoir is accounted for in PA calculations.

Future boreholes could affect the hydraulic conditions in the disposal system. Intersection of pockets of pressurized gas and brine would likely result in short-term, isolated hydraulic disturbances, and will not affect the hydrology of the disposal system significantly. Potentially the most significant hydraulic disturbance to the disposal system could occur if an uncontrolled blowout during drilling resulted in substantial flow through the borehole from a pressurized zone to a thief zone. For example, if a borehole penetrates a brine reservoir in the Castile, brine could flow through the borehole to the Culebra, and, as a result, could affect hydraulic conditions in the Culebra. The potential effects of such an event can be compared to the effects of long-term fluid flow from deep overpressurized units to the Culebra through abandoned boreholes. Wallace (Wallace 1996a) analyzed the potential effects of such interconnections in the future within the controlled area (but that do not intersect waste), and concluded that flow through abandoned boreholes between the Culebra and deep units could be eliminated from PA calculations on the basis of low consequence.

SCR-5.2.1.4 **FEP Number:** H24
FEP Title: *Drilling-Induced Geochemical Changes*

SCR-5.2.1.4.1 Screening Decision: UP (HCN)
DP (Future)

Drilling-Induced Geochemical Changes that occur within the controlled area as a result of HCN and future drilling-induced flow are accounted for in PA calculations.

SCR-5.2.1.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.4.3 Screening Argument

Borehole circulation fluid could be lost to thief zones encountered during drilling, or fluid could flow from pressurized zones through the borehole to the land surface (blowout) or to a thief zone. Such drilling-related EPs could influence groundwater flow and, potentially, radionuclide transport in the affected units. Future drilling within the controlled area could result in direct releases of radionuclides to the land surface or transport of radionuclides between hydraulically conductive units.

Movement of brine from a pressurized zone through a borehole and into potential thief zones such as the Salado interbeds or the Culebra, could result in geochemical changes and altered radionuclide migration rates in these units.

SCR-5.2.1.4.3.1 Historical, Current, and Near-Future Human EPs

Drilling associated with resource exploration, exploitation, and recovery has taken place or is currently taking place outside the controlled area in the Delaware Basin. These drilling activities are expected to continue in the vicinity of the WIPP in the near future. Chemical changes induced by such drilling are discussed below.

SCR-5.2.1.4.3.2 Geochemical Effects of Drilling-Induced Flow–HCN

Radionuclide migration rates are governed by the coupled effects of hydrological and geochemical processes (see discussions in FEPs W77 through W100, Section SCR-6.6.1.1, Section SCR-6.6.1.2, Section SCR-6.6.2.1, Section SCR-6.6.3.1, Section SCR-6.6.3.2, Section SCR-6.6.4.1, Section SCR-6.7.1.1, Section SCR-6.7.2.1, Section SCR-6.7.3.1, Section SCR-6.7.4.1, Section SCR-6.7.4.2, Section SCR-6.7.4.3, Section SCR-6.7.5.1, Section SCR-6.7.5.2, Section SCR-6.7.5.3, and Section SCR-6.7.5.4). Human EPs outside the controlled area could affect the geochemistry of units within the controlled area if they occur sufficiently close to the edge of the controlled area. Movement of brine from a pressurized reservoir in the Castile through a borehole into potential thief zones, such as the Salado interbeds or the Culebra, could cause drilling-induced geochemical changes resulting in altered radionuclide migration rates in these units through their effects on colloid transport and sorption (colloid transport may enhance radionuclide migration, while radionuclide migration may be retarded by sorption).

The treatment of colloids in PA calculations is described in the CCA, Chapter 6.0, Section 6.4.3.6 and Section 6.4.6.2.2. The repository and its contents provide the main source of colloids in the disposal system. By comparison, Castile brines have relatively low total colloid concentrations. Therefore, changes in colloid transport in units within the controlled area as a result of HCN drilling-induced flow have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Sorption within the Culebra is accounted for in PA calculations as discussed in the CCA, Chapter 6.0, Section 6.4.6.2. The sorption model comprises an equilibrium, sorption isotherm approximation, employing K_ds applicable to dolomite in the Culebra (Appendix PA-2004, Attachment MASS, Section MASS-15.2). The cumulative distribution functions (CDFs) of K_ds used in PA were modified in the CRA-2009 PABC as a result of EPA comments (Clayton 2009). These values are also used in the CRA-2014. Any changes in sorption geochemistry in the Culebra within the controlled area as a result of HCN drilling-induced flow are accounted for in PA calculations.

Sorption within the Dewey Lake is accounted for in PA calculations, as discussed in the CCA, Chapter 6.0, Section 6.4.6.6. It is assumed that the sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter the Dewey Lake from being released over 10,000 yrs (Wallace et al. 1995). Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of changes in sorption in the Dewey Lake and other units within the controlled area as a result of HCN drilling-induced flow have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.4.3.3 Future Human EPs — Boreholes that Intersect the Waste Disposal Region

The consequences of drilling within the controlled area in the future will primarily depend on the location of the borehole. Future deep drilling could potentially penetrate the waste disposal region. If the borehole intersects the waste in the disposal rooms, radionuclides could be transported as a result of drilling fluid flow and geochemical conditions in the waste panel could be affected as a result of drilling induced geochemical changes.

SCR-5.2.1.4.3.4 Future Human EPs — Boreholes That Do Not Intersect the Waste Disposal Region

Future boreholes that do not intersect the waste disposal region could nevertheless encounter contaminated material by intersecting a region into which radionuclides have migrated from the disposal panels, or could affect hydrogeological conditions within the disposal system. Consistent with the containment requirements in section 191.13(a), PAs need not evaluate the effects of the intersection of contaminated material outside the controlled area.

Movement of brine from a pressurized reservoir in the Castile, through a borehole and into thief zones such as the Salado interbeds or the Culebra could result in drilling-induced geochemical changes and altered radionuclide migration rates in these units.

SCR-5.2.1.4.3.5 Geochemical Effects of Drilling-Induced Flow

Movement of brine from a pressurized reservoir in the Castile through a borehole into thief zones, such as the Salado interbeds or the Culebra, could cause geochemical changes resulting in altered radionuclide migration rates in these units through their effects on colloid transport and sorption.

The contents of the waste disposal panels provide the main source of colloids in the disposal system. Thus, consistent with the discussion in FEPs H21, H22, and H23 (Section SCR-5.2.1.1, Section SCR-5.2.1.2, and SCR-5.2.1.3), colloid transport as a result of drilling-induced flow associated with future boreholes that do not intersect the waste disposal region has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

As discussed in FEPs H21, H22, and H23 (Section SCR-5.2.1.1, Section SCR-5.2.1.2, and SCR-5.2.1.3), sorption within the Culebra is accounted for in PA calculations. The sorption model accounts for the effects of changes in sorption in the Culebra as a result of drilling-induced flow associated with boreholes that do not intersect the waste disposal region.

Consistent with the screening discussion in FEPs H21, H22, and H23 (Section SCR-5.2.1.1, Section SCR-5.2.1.2, and SCR-5.2.1.3), the effects of changes in sorption in the Dewey Lake within the controlled area as a result of drilling-induced flow associated with boreholes that do not intersect the waste disposal region have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

In summary, the effects of drilling-induced geochemical changes that occur within the controlled area as a result of HCN and future drilling-induced flow are accounted for in PA calculations. Those that occur outside the controlled area have been eliminated from PA calculations.

SCR-5.2.1.5 **FEP Numbers:** H25 and H26
FEP Titles: *Oil and Gas Extraction*
Groundwater Extraction

SCR-5.2.1.5.1 Screening Decision: SO-C (HCN)
SO-R (Future)

HCN *Groundwater Extraction* and *Oil and Gas Extraction* outside the controlled area has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. *Groundwater Extraction* and *Oil and Gas Extraction* through future boreholes has been eliminated from PA calculations on regulatory grounds.

SCR-5.2.1.5.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.5.2.1 Screening Argument

The extraction of fluid could alter fluid-flow patterns in the target horizons, or in overlying units as a result of a failed borehole casing. Also, the removal of confined fluid from oil- or gas-bearing units can cause compaction in some geologic settings, potentially resulting in subvertical fracturing and surface subsidence.

SCR-5.2.1.5.2.2 Historical, Current, and Near-Future Human EPs

As discussed in FEPs H25 through H36, water, oil, and gas production are the only activities involving fluid extraction through boreholes that have taken place or are currently taking place in the vicinity of the WIPP. These activities are expected to continue in the vicinity of the WIPP in the near future.

Groundwater extraction outside the controlled area from formations above the Salado could affect groundwater flow. The Dewey Lake contains a productive zone of saturation south of the WIPP site. Several wells operated by the J.C. Mills Ranch south of the WIPP produce water from the Dewey Lake to supply livestock (see the CCA, Chapter 2.0, Section 2.2.1.4.2.1). Water has also been extracted from the Culebra at the Engle Well approximately 9.66 km (6 mi) south of the controlled area to provide water for livestock. Additionally, a water well at the Sandia National Laboratories wellpad SNL-14 also provides livestock water for the Mills ranch. This well is approximately 3,000 ft (0.9 km) from the WIPP site boundary.

If contaminated water intersects a well while it is producing, then contaminants could be pumped to the surface. Consistent with the containment requirements in section 191.13(a), PAs need not evaluate radiation doses that might result from such an event. However, compliance assessments must include any such events in dose calculations for evaluating compliance with the individual protection requirements in section 191.15. For undisturbed conditions, there are no radionuclide releases to units above the Salado, and therefore no releases to the accessible environment or producing water wells in the area (Appendix IGP-2014 and Section 53).

Pumping from wells at the J.C. Mills Ranch may have resulted in reductions in hydraulic head in the Dewey Lake within southern regions of the controlled area, leading to increased hydraulic head gradients. However, these changes in the groundwater flow conditions in the Dewey Lake will have no significant effects on the performance of the disposal system, primarily because of the sorptive capacity of the Dewey Lake (see the CCA, Chapter 6.0, Section 6.4.6.6). Retardation of any radionuclides that enter the Dewey Lake will be such that no radionuclides will migrate through the Dewey Lake to the accessible environment within the 10,000-yr regulatory period.

The effects of groundwater extraction from the Culebra from a well 9.66 km (6 mi) south of the controlled area have been evaluated by Wallace (Wallace 1996b), using an analytical solution for Darcian fluid flow in a continuous porous medium. Wallace (Wallace 1996b) showed that such a well pumping at about 1.9 liters (L) (0.5 gallon [gal]) per minute for 10,000 yrs will induce a hydraulic head gradient across the controlled area of about 4×10^{-5}. The hydraulic head gradient across the controlled area currently ranges from between 0.001 to 0.007. Therefore, pumping from the Engle Well will have only minor effects on the hydraulic head gradient within the controlled area even if pumping were to continue for 10,000 yrs. Thus, the effects of HCN groundwater extraction outside the controlled area have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Oil and gas extraction outside the controlled area could affect the hydrology of the disposal system. However, the horizons that act as oil and gas reservoirs are sufficiently below the repository for changes in fluid-flow patterns to be of low consequence, unless there is fluid leakage through a failed borehole casing. Also, oil and gas extraction horizons in the Delaware Basin are well-lithified rigid strata, so oil and gas extraction is not likely to result in compaction and subsidence (Brausch et al. 1982, pp. 52, 61). Furthermore, the plasticity of the salt formations in the Delaware Basin will limit the extent of any fracturing caused by compaction of underlying units. Thus, neither the extraction of gas from reservoirs in the Morrow Formation (some 4,200 m (14,000 ft) below the surface), nor extraction of oil from the shallower units within the Delaware Mountain Group (about 1,250 to 2,450 m (about 4,000 to 8,000 ft) below the surface) will lead to compaction and subsidence. In summary, historical, current, and near-future oil and gas extraction outside the controlled area has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.5.2.3 Future Human EPs

Consistent with section 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, groundwater extraction and oil and gas extraction through future boreholes have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.1.6 **FEP Numbers:** H27, H28, and H29

FEP Titles: *Liquid Waste Disposal – OB* (H27)
Enhanced Oil and Gas Production – OB (H28)
Hydrocarbon Storage – OB (H29)

SCR-5.2.1.6.1 Screening Decision: SO-C (HCN)
SO-C (Future)

The hydrological effects of HCN fluid injection (*Liquid Waste Disposal*, *Enhanced Oil and Gas Production*, and *Hydrocarbon Storage*) through boreholes outside the controlled area have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. *Liquid Waste Disposal*, *Enhanced Oil and Gas Production*, and *Hydrocarbon Storage* in the future have been eliminated from PA calculations based on low consequence.

SCR-5.2.1.6.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.6.3 Screening Argument

The injection of fluids could alter fluid-flow patterns in the target horizons or, if there is accidental leakage through a borehole casing, in any other intersected hydraulically conductive zone. Injection of fluids through a leaking borehole could also result in geochemical changes and altered radionuclide migration rates in the thief units.

SCR-5.2.1.6.3.1 Historical, Current, and Near-Future Human EPs

The only historical and current activities involving fluid injection through boreholes in the Delaware Basin are enhanced oil and gas production (waterflooding or carbon dioxide (CO_2) injection), hydrocarbon storage (gas reinjection), and liquid waste disposal (byproducts from oil and gas production). These fluid injection activities are expected to continue in the vicinity of the WIPP in the near future.

Hydraulic fracturing of oil- or gas-bearing units is currently used to improve the performance of hydrocarbon reservoirs in the Delaware Basin. Fracturing is induced during a short period of high-pressure fluid injection, resulting in increased hydraulic conductivity near the borehole. Normally, this controlled fracturing is confined to the pay zone and is unlikely to affect overlying strata.

Secondary production techniques, such as waterflooding, that are used to maintain reservoir pressure and displace oil are currently employed in hydrocarbon reservoirs in the Delaware Basin (Brausch et al. 1982, pp. 29-30). Tertiary recovery techniques, such as CO_2 miscible flooding, have been implemented with limited success in the Delaware Basin, but CO_2 miscible flooding is not an attractive recovery method for reservoirs near the WIPP (Melzer 2013). Even if CO_2 flooding were to occur, the effects, if any, would be very similar to those associated with waterflooding.

Reinjection of gas for storage currently takes place at one location in the Delaware Basin in a depleted gas field in the Morrow Formation at the Washington Ranch near Carlsbad Caverns (Burton et al. 1993, pp. 66-67; Appendix DATA-2004, Attachment A). This field is too far from the WIPP site to have any effect on WIPP groundwaters under any circumstances. Disposal of liquid by-products from oil and gas production involves injection of fluid into depleted reservoirs. Such fluid injection techniques result in repressurization of the depleted target reservoir and mitigates any effects of fluid withdrawal.

The most significant effects of fluid injection would arise from substantial and uncontrolled fluid leakage through a failed borehole casing. The highly saline environment of some units can promote rapid corrosion of well casings and may result in fluid loss from boreholes.

SCR-5.2.1.6.3.2 Hydraulic Effects of Leakage through Injection Boreholes

The Vacuum Field (located in the Capitan Reef, some 30 km [20 mi] northeast of the WIPP site) and the Rhodes-Yates Field (located in the back reef of the Capitan, some 70 km (45 mi) southeast of the WIPP site) have been waterflooded for 40 yrs with confirmed leaking wells, which have resulted in brine entering the Salado and other formations above the Salado (see, for example, Silva 1994, pp. 67-68). Currently, saltwater disposal takes place in the vicinity of the WIPP into formations below the Castile. However, leakages from saltwater disposal wells or waterflood wells in the near future in the vicinity of the WIPP are unlikely to occur because of the following:

- There are significant differences between the geology and lithology in the vicinity of the disposal system and that of the Vacuum and Rhodes-Yates Fields. The WIPP is located in the Delaware Basin in a fore-reef environment, where a thick zone of anhydrite and halite (the Castile) exists. In the vicinity of the WIPP, oil is produced from the Brushy Canyon Formation at depths greater than 2,100 m (7,000 ft). By contrast, the Castile is not present at either the Vacuum or the Rhodes-Yates Field, which lie outside the Delaware Basin. Oil production at the Vacuum Field is from the San Andres and Grayburg Formations at depths of approximately 1,400 m (4,500 ft), and oil production at the Rhodes-Yates Field is from the Yates and Seven Rivers Formations at depths of approximately 900 m (3,000 ft). Waterflooding at the Rhodes-Yates Field involves injection into a zone only 60 m (200 ft) below the Salado. There are more potential thief zones below the Salado near the WIPP than at the Rhodes-Yates or Vacuum Fields; the Salado in the vicinity of the WIPP is therefore less likely to receive any fluid that leaks from an injection borehole. Additionally, the oil pools in the vicinity of the WIPP are characterized by channel sands with thin net pay zones, low permeabilities, high irreducible water saturations, and high residual oil saturations. Therefore, waterflooding of oil fields in the vicinity of the WIPP on the scale of that undertaken in the Vacuum or the Rhodes-Yates Field is unlikely.

- New Mexico state regulations require the emplacement of a salt isolation casing string for all wells drilled in the potash enclave, which includes the WIPP area, to reduce the possibility of petroleum wells leaking into the Salado. Also, injection pressures are not allowed to exceed the pressure at which the rocks fracture. The injection pressure gradient must be kept below 4.5×10^3 pascals per meter above hydrostatic if fracture pressures are unknown. Such controls on fluid injection pressures limit the potential magnitude of any leakages from injection boreholes.

- Recent improvements in well completion practices and reservoir operations management have reduced the occurrences of leakages from injection wells. For example, injection pressures during waterflooding are typically kept below about 23×10^3 pascals per meter to avoid fracture initiation. Also, wells are currently completed using cemented and perforated casing, rather than the open-hole completions used in the early Rhodes-Yates wells.

Any injection well leakages that do occur in the vicinity of the WIPP in the near future are more likely to be associated with liquid waste disposal than waterflooding. Disposal typically involves fluid injection though old and potentially corroded well casings and does not include monitoring to the same extent as waterflooding. Such fluid injection could affect the performance of the disposal system if sufficient fluid leaked into the Salado interbeds to affect the rate of brine flow into the waste disposal panels.

Stoelzel and O'Brien (Stoelzel and O'Brien 1996) evaluated the potential effects on the disposal system of leakage from a hypothetical salt water disposal borehole near the WIPP. Stoelzel and O'Brien (Stoelzel and O'Brien 1996) used the two-dimensional BRAGFLO model (vertical north-south cross-section) to simulate saltwater disposal to the north and to the south of the disposal system. The disposal system model included the waste disposal region, the marker beds (MBs) and anhydrite intervals near the excavation horizon, and the rock strata associated with local oil and gas developments. A worst-case simulation was run using high values of borehole and anhydrite permeability and a low value of halite permeability to encourage flow to the disposal panels via the anhydrite. The boreholes were assumed to be plugged immediately above the Salado (consistent with the plugging configurations described in the CCA, Chapter 6.0, Section 6.4.7.2). Saltwater disposal into the Upper Bell Canyon was simulated, with annular leakage through the Salado. A total of approximately 7×10^5 m^3 (2.47×10^7 ft^3) of brine was injected through the boreholes during a 50-yr simulated disposal period. In this time, approximately 50 m^3 (1,765.5 ft^3) of brine entered the anhydrite interval at the horizon of the waste disposal region. For the next 200 yrs, the boreholes were assumed to be abandoned (with open-hole permeabilities of 1×10^{-9} square meters (m^2) (4×10^{-8} $in.^2$)). Cement plugs (of permeability 1×10^{-17} m^2 (4×10^{-16} $in.^2$)) were assumed to be placed at the injection interval and at the top of the Salado. Subsequently, the boreholes were prescribed the permeability of silty sand (see the CCA, Chapter 6.0, Section 6.4.7.2), and the simulation was continued until the end of the 10,000-yr regulatory period. During this period, approximately 400 m^3 (14,124 ft^3) of brine entered the waste disposal region from the anhydrite interval. This value of cumulative brine inflow is within the bounds of the values generated by PA calculations for the UP scenario. During the disposal well simulation, leakage from the injection boreholes would have had no significant effect on the inflow rate at the waste panels.

Stoelzel and Swift (Stoelzel and Swift 1997) expanded on Stoelzel and O'Brien's (Stoelzel and O'Brien 1996) work by considering injection for a longer period of time (up to 150 yrs) and into deeper horizons at higher pressures. They developed two computational models (a modified cross-sectional model and an axisymmetric radial model) that are alternatives to the cross-sectional model used by Stoelzel and O'Brien (Stoelzel and O'Brien 1996). Rather than repeat the conservative and bounding approach used by Stoelzel and O'Brien (Stoelzel and O'Brien 1996), Stoelzel and Swift (Stoelzel and Swift 1997) focused on reasonable and realistic conditions for most aspects of the modeling, including setting parameters that were sampled in the CCA at their median values. Model results indicate that, for the cases considered, the largest volume of brine entering MB 139 (the primary pathway to the WIPP) from the borehole is approximately 1,500 m^3 (52,974 ft^3), which is a small enough volume that it would not affect Stoelzel and O'Brien's (Stoelzel and O'Brien 1996) conclusion even if it somehow all reached the WIPP. Other cases showed from 0 to 600 m^3 (21,190 ft^3) of brine entering MB 139 from the injection well. In all cases, high-permeability fractures created in the Castile and Salado anhydrite layers by the modeled injection pressures were restricted to less than 400 m (1,312 ft) from the wellbore, and did not extend more than 250 m in MB 138 and MB 139.

No flow entered MB 139, nor was fracturing of the unit calculated to occur away from the borehole, in cases in which leaks in the cement sheath had permeabilities of $10^{-12.5}$ m^2 (corresponding to the median value used to characterize fully degraded boreholes in the CCA) or lower. The cases modeled in which flow entered MB 139 from the borehole and fracturing occurred away from the borehole required injection pressures conservatively higher than any currently in use near the WIPP and either 150 yrs of leakage through a fully degraded cement sheath or 10 yrs of simultaneous tubing and casing leaks from a waterflood operation. These conditions are not likely to occur in the future. If leaks like these do occur from brine injection near the WIPP, however, results of the Stoelzel and Swift (Stoelzel and Swift 1997) modeling study indicate that they will not affect the performance of the repository.

Thus, the hydraulic effects of leakage through HCN boreholes outside the controlled area have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.6.3.3 Effects of Density Changes Resulting from Leakage Through Injection Boreholes

Leakage through a failed borehole casing during a fluid injection operation in the vicinity of the WIPP could alter fluid density in the affected unit, which could result in changes in fluid flow rates and directions within the disposal system. Disposal of oil and gas production byproducts through boreholes could increase fluid densities in transmissive units affected by leakage in the casing. Operations such as waterflooding use fluids derived from the target reservoir, or fluids with a similar composition, to avoid scaling and other reactions. Therefore, the effects of leakage from waterflood boreholes would be similar to leakage from disposal wells.

Denser fluids have a tendency to sink relative to less dense fluids, and, if the hydrogeological unit concerned has a dip, there will be a tendency for the dense fluid to travel in the downdip direction. If this direction is the same as the direction of the groundwater pressure gradient, there would be an increase in flow velocity, and conversely, if the downdip direction is opposed to the direction of the groundwater pressure gradient, there would be a decrease in flow velocity. In general terms, taking account of density-related flow will cause a rotation of the flow vector towards the downdip direction that is dependent on the density contrast and the dip.

Wilmot and Galson (Wilmot and Galson 1996) showed that brine density changes in the Culebra resulting from leakage through an injection borehole outside the controlled area will not affect fluid flow in the Culebra significantly. Potash mining activities assumed on the basis of regulatory criteria to occur in the near future outside the controlled area will have a more significant effect on modeled Culebra hydrology. The distribution of existing leases suggests that near-future mining will take place to the north, west, and south of the controlled area (see the CCA, Chapter 2.0, Section 2.3.1.1). The effects of such potash mining are accounted for in calculations of UP of the disposal system (through an increase in the transmissivity of the Culebra above the mined region, as discussed in FEPs H37, H38, and H39 [Section SCR-5.2.2.1, Section SCR-5.2.2.2, and Section SCR-5.2.3.1]). Groundwater modeling that accounts for potash mining shows a change in the fluid pressure distribution and a consequent shift of flow directions towards the west in the Culebra within the controlled area (Wallace 1996c). A localized increase in fluid density in the Culebra resulting from leakage from an injection borehole would rotate the flow vector towards the downdip direction (towards the east).

Wilmot and Galson (Wilmot and Galson 1996) compared the relative magnitudes of the freshwater head gradient and the gravitational gradient and showed that the density effect is of low consequence to the performance of the disposal system. According to Darcy's Law, flow in an isotropic porous medium is governed by the gradient of fluid pressure and a gravitational term

$$\overline{v} = -\frac{k}{\mu}\left[\nabla p - \rho \overline{g}\right] \qquad \text{(SCR.7)}$$

where

v	=	Darcy velocity vector	(m s^{-1})
k	=	intrinsic permeability	(m^2)
μ	=	fluid viscosity	(Pa s)
∇p	=	gradient of fluid pressure	(Pa m^{-1})
ρ	=	fluid density	(kg m^{-3})
g	=	gravitational acceleration vector	(m s^{-2})

The relationship between the gravity-driven flow component and the pressure-driven component can be shown by expressing the velocity vector in terms of a freshwater head gradient and a density-related elevation gradient

$$\overline{v} = -K\left[\nabla H_f + \frac{\Delta\rho}{\rho_f}\nabla E\right] \qquad \text{(SCR.8)}$$

where

K	=	hydraulic conductivity	(m s^{-1})
∇H_f	=	gradient of freshwater head	
$\Delta\rho$	=	difference between actual fluid density and reference fluid density	(kg m^{-3})
ρ_f	=	density of freshwater	(kg m^{-3})
∇E	=	gradient of elevation	

Davies (Davies 1989, p. 28) defined a driving force ratio (DFR) to assess the potential significance of the density gradient

$$DFR = \frac{\Delta\rho\left|\nabla E\right|}{\rho_f\left|\nabla H_f\right|} \qquad \text{(SCR.9)}$$

and concluded that a DFR of 0.5 can be considered an approximate threshold at which density-related gravity effects may become significant (Davies 1989, p. 28).

The dip of the Culebra in the vicinity of the WIPP is about 0.44 degrees or 8 m/km (26 ft/mi) to the east (Davies 1989, p. 42). According to Davies (Davies 1989, pp. 47–48), freshwater head gradients in the Culebra between the waste panels and the southwestern and western boundaries of the accessible environment range from 4 m/km (13 ft/mi) to 7 m/km (23 ft/mi). Only small changes in gradient arise from the calculated effects of near-future mining. Culebra brines have densities ranging from 998 to 1,158 kilograms per cubic meter (kg/m^3) (998 to 1,158 parts per million [ppm]) (Cauffman et al. 1990, Table E1.b). Assuming the density of fluid leaking from a waterflood borehole or a disposal well to be 1,215 kg/m^3 (1,215 ppm) (a conservative high value similar to the density of Castile brine [Popielak et al. 1983, Table C-2]) leads to a DFR of between 0.07 and 0.43. These values of the DFR show that density-related effects caused by leakage of brine into the Culebra during fluid injection operations are not significant.

In summary, the effects of HCN fluid injection (liquid waste disposal, enhanced oil and gas production, and hydrocarbon storage) through boreholes outside the controlled area have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.6.3.4 Geochemical Effects of Leakage through Injection Boreholes

Injection of fluids through a leaking borehole could affect the geochemical conditions in thief zones, such as the Salado interbeds or the Culebra. Such fluid injection-induced geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area through their effects on colloid transport and sorption.

The majority of fluids injected (for example, during brine disposal) have been extracted locally during production activities. Because they have been derived locally, their compositions are similar to fluids currently present in the disposal system, and they will have low total colloid concentrations compared to those in the waste disposal panels (see FEPs discussion for H21 through H24, Section SCR-5.2.1.1, Section SCR-5.2.1.2, Section SCR-5.2.1.3, and SCR-5.2.1.4). The repository will remain the main source of colloids in the disposal system. Therefore, colloid transport as a result of HCN fluid injection has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

As discussed in FEPs H21 through H24 (Section SCR-5.2.1.1, Section SCR-5.2.1.2, Section SCR-5.2.1.3, and SCR-5.2.1.4), sorption within the Culebra is accounted for in PA calculations. The sorption model used accounts for the effects of any changes in sorption in the Culebra as a result of leakage through HCN injection boreholes.

Consistent with the screening discussion in FEPs H21 through H24, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of leakage through HCN injection boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

Non-locally derived fluids could be used during hydraulic fracturing operations. However, such fluid-injection operations would be carefully controlled to minimize leakage to thief zones. Therefore, any potential geochemical effects of such leakages have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.6.3.5 Future Human EPs

Consistent with section 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole within the site boundary. Liquid waste disposal (byproducts from oil and gas production), enhanced oil and gas production, and hydrocarbon storage are techniques associated with resource recovery and are expected to continue into the future outside the site boundary. Analyses have shown that these activities have little consequence on repository performance (Stoelzel and Swift 1997). Therefore, activities such as liquid waste disposal, enhanced oil and gas production, and hydrocarbon storage outside the site boundary have been eliminated from PA calculations on the basis of low consequence.

SCR-5.2.1.7

FEP Numbers:	H60, H61, and H62
FEP Titles:	*Liquid Waste Disposal – IB* (H60) *Enhanced Oil and Gas Production – IB* (H61) *Hydrocarbon Storage – IB* (H62)

SCR-5.2.1.7.1 Screening Decision: SO-R (HCN)
SO-R (Future)

The hydrological effects of HCN fluid injection (*Liquid Waste Disposal*, *Enhanced Oil and Gas Production*, and *Hydrocarbon Storage*) through boreholes inside the controlled area have been eliminated from PA calculations on regulatory grounds (section 194.25(a)). *Liquid Waste Disposal*, *Enhanced Oil and Gas Production*, and *Hydrocarbon Storage* (within the controlled area) in the future have been eliminated from PA calculations on regulatory grounds (section 194.33(d)).

SCR-5.2.1.7.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.7.3 Screening Argument

The injection of fluids in a borehole within the WIPP boundary could alter fluid-flow patterns in the target horizons or, if there is accidental leakage through a borehole casing, in any other intersected hydraulically conductive zone. Injection of fluids through a leaking borehole within the WIPP boundary could also result in geochemical changes and altered radionuclide migration rates in the thief units.

SCR-5.2.1.7.3.1 Historical, Current, and Near-Future Human EPs

Injection of fluids for the purposes of liquid disposal, enhanced oil and gas production, or hydrocarbon storage has not occurred within the WIPP boundary. Therefore, based on the future states assumption provided by section 194.25(a), it is assumed that such activities will not occur within the near-future time frame, which includes the period of WIPP AICs. These activities are excluded from PA calculations on regulatory grounds.

SCR-5.2.1.7.3.2 Future Human EPs

The provisions of section 194.33(d) state, "that performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole." Therefore, the future injection of fluids for the purposes of liquid disposal, enhanced oil and gas production, and hydrocarbon storage within the WIPP boundary have been excluded from PA calculations on regulatory grounds.

SCR-5.2.1.8 **FEP Number:** H30
FEP Title: *Fluid Injection-Induced Geochemical Changes*

SCR-5.2.1.8.1 Screening Decision: UP (HCN)
SO-R (Future)

Geochemical changes that occur inside the controlled area as a result of fluid flow associated with HCN fluid injection are accounted for in PA calculations. Geochemical changes resulting from fluid injection in the future inside the controlled area have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.1.8.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.8.3 Screening Argument

The injection of fluids could alter fluid-flow patterns in the target horizons or, if there is accidental leakage through a borehole casing, in any other intersected hydraulically conductive zone. Injection of fluids through a leaking borehole could also result in geochemical changes and altered radionuclide migration rates in the thief units.

SCR-5.2.1.8.3.1 Geochemical Effects of Leakage through Injection Boreholes

Injection of fluids through a leaking borehole could affect the geochemical conditions in thief zones, such as the Salado interbeds or the Culebra. Such fluid injection-induced geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area through their effects on colloid transport and sorption.

The majority of fluids injected (for example, during brine disposal) have been extracted locally during production activities. Because they have been derived locally, their compositions are similar to fluids currently present in the disposal system, and they will have low total colloid concentrations compared to those in the waste disposal panels (see FEPs H21 through H24, Section SCR-5.2.1.1, Section SCR-5.2.1.2, Section SCR-5.2.1.3, and SCR-5.2.1.4). The repository will remain the main source of colloids in the disposal system. Therefore, colloid transport as a result of HCN fluid injection has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

As discussed in FEPs H21 through H24 (Section SCR-5.2.1.1, Section SCR-5.2.1.2, Section SCR-5.2.1.3, and SCR-5.2.1.4), sorption within the Culebra is accounted for in PA calculations. The sorption model used accounts for the effects of any changes in sorption in the Culebra as a result of leakage through HCN injection boreholes.

Consistent with the screening discussion in FEPs H21 through H24, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of leakage through HCN injection boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

Non-locally derived fluids could be used during hydraulic fracturing operations. However, such fluid injection operations would be carefully controlled to minimize leakage to thief zones. Therefore, any potential geochemical effects of such leakages have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.8.3.2 Future Human EPs

Consistent with section 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Liquid waste disposal (byproducts from oil and gas production), enhanced oil and gas production, and hydrocarbon storage are techniques associated with resource recovery. Therefore, the use of future boreholes for such activities and fluid injection-induced geochemical changes have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.1.9 **FEP Number:** H31
FEP Title: *Natural Borehole Fluid Flow* (H31)

SCR-5.2.1.9.1 Screening Decision: SO-C (HCN)
SO-C (Future, holes not penetrating waste panels)
DP (Future, holes through waste panels)

The effects of *Natural Borehole Fluid Flow* through existing or near-future abandoned boreholes, known or unknown, have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. *Natural Borehole Fluid Flow* through a future borehole that intersects a waste panel is accounted for in PA calculations. The effects of *Natural Borehole Fluid Flow* through a future borehole that does not intersect the waste-disposal region have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.9.2 Summary of New Information

Probabilities for the various borehole types used in PA have been updated based on information gathered by the Delaware Basin Monitoring Program. These updated probabilities do not impact or change the screening arguments or decisions, but are incorporated into PA in an effort to reflect current technologies and methods used in industry. These PA parameters are described in Camphouse (Camphouse 2013a).

SCR-5.2.1.9.3 Screening Argument

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

Potentially, boreholes could provide pathways for surface-derived water or groundwater to percolate through low-permeability strata and into formations containing soluble minerals. Large-scale dissolution through this mechanism could lead to subsidence and to changes in groundwater flow patterns. Also, fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation.

SCR-5.2.1.9.3.1 Historical, Current, and Near-Future Human EPs

Abandoned water, potash, oil, and gas exploration and production boreholes exist within and outside the controlled area. Most of these boreholes have been plugged in some way, but some have simply been abandoned. Over time, even the boreholes that have been plugged may provide hydraulic connections among the units they penetrate as the plugs degrade. The DOE assumes that records of past and present drilling activities in New Mexico are largely accurate and that evidence of most boreholes would be included in these records. However, the potential effects of boreholes do not change depending on whether their existence is known, hence flow through undetected boreholes and flow through detected boreholes can be evaluated together.

SCR-5.2.1.9.3.2 Hydraulic Effects of Flow through Abandoned Boreholes

Fluid flow and radionuclide transport within the Culebra could be affected if deep boreholes result in hydraulic connections between the Culebra and deep, overpressurized or underpressurized units, or if boreholes provide interconnections for flow between shallow units.

SCR-5.2.1.9.3.3 Connections Between the Culebra and Deeper Units

Fluid flow and radionuclide transport within the Culebra could be affected if deep boreholes result in hydraulic connections between the Culebra and deep, overpressurized or underpressurized units. Over the past 80 yrs, a large number of deep boreholes have been drilled within and around the controlled area (see the CCA, Chapter 6.0, Section 6.4.12.2). The effects on the performance of the disposal system of long-term hydraulic connections between the Culebra and deep units depends on the locations of the boreholes. In some cases, changes in the Culebra flow field caused by interconnections with deep units could decrease lateral radionuclide travel times to the accessible environment.

As part of an analysis to determine the impact of such interconnections, Wallace (Wallace 1996a) gathered information on the pressures, permeabilities, and thicknesses of potential oil- or gas-bearing sedimentary units; such units exist to a depth of about 5,500 m (18,044 ft) in the vicinity of the WIPP. Of these units, the Atoka, some 4,000 m (13,123 ft) below the land surface, has the highest documented pressure of about 64 megapascals (MPa) (9,600 pounds per square inch [psi]), with permeability of about 2×10^{-14} m^2 (2.1×10^{-13} square ft [ft^2]) and thickness of about 210 m (689 ft). The Strawn, 3,900 m (12,795 ft) below the land surface, has the lowest pressures (35 MPa [5,000 psi], which is lower than hydrostatic) and highest permeability (10^{-13} m^2 [1.1×10^{-12} ft^2]) of the deep units, with a thickness of about 90 m (295 ft).

PA calculations indicate that the shortest radionuclide travel times to the accessible environment through the Culebra occur when flow in the Culebra in the disposal system is from north to south. Wallace (Wallace 1996a) ran the steady-state SECOFL2D model with the PA data that generated the shortest radionuclide travel times (with and without mining in the controlled area) but perturbed the flow field by placing a borehole connecting the Atoka to the Culebra just north of the waste disposal panels and a borehole connecting the Culebra to the Strawn just south of the controlled area. The borehole locations were selected to coincide with the end points of the fastest flow paths modeled, which represents an unlikely worst-case condition. Although the Atoka is primarily a gas-bearing unit, Wallace (Wallace 1996a) assumed that the unit is brine saturated. This assumption is conservative because it prevents two-phase flow from occurring in the Culebra, which would decrease the water permeability and thereby increase transport times. It was conservatively assumed that the pressure in the Atoka would not have been depleted by production before the well was plugged and abandoned. Furthermore, it was conservatively assumed that all flow from the Atoka would enter the Culebra and not intermediate or shallower units, and that flow from the Culebra could somehow enter the Strawn despite intermediate zones having higher pressures than the Culebra. The fluid flux through each borehole was determined using Darcy's Law, assuming a borehole hydraulic conductivity of 10^{-4} m/s (for a permeability of about 10^{-11} m^2 [1.1×10^{-10} ft^2]) representing silty sand, a borehole radius of 0.25 m (.82 ft), and a fluid pressure in the Culebra of 0.88 MPa (132 psi) at a depth of about 200 m (650 ft). With these parameters, the Atoka was calculated to transmit water to the Culebra at about 1.4 × 10^{-5} m^3/s (0.22 gallons per minute [gpm]), and the Strawn was calculated to receive water from the Culebra at about 1.5 × 10^{-6} m^3/s (0.024 gpm).

Travel times through the Culebra to the accessible environment were calculated using the SECOFL2D velocity fields for particles released to the Culebra above the waste panels, assuming no retardation by sorption or diffusion into the rock matrix. Mean Darcy velocities were then determined from the distance each radionuclide traveled, the time taken to reach the accessible environment, and the effective Culebra porosity. The results show that, at worst, interconnections between the Culebra and deep units under the unrealistically conservative assumptions listed above could cause less than a twofold increase in the largest mean Darcy velocity expected in the Culebra in the absence of such interconnections.

These effects can be compared to the potential effects of climate change on gradients and flow velocities through the Culebra. As discussed in the CCA, Chapter 6.0, Section 6.4.9 and Corbet and Knupp (Corbet and Knupp 1996), the maximum effect of a future, wetter climate would be to raise the water table to the ground surface. This would raise heads and gradients in all units above the Salado. For the Culebra, the maximum change in gradient was estimated to be about a factor of 2.1. The effect of climate change is incorporated in compliance calculations through the Climate Index, which is used as a multiplier for Culebra groundwater velocities. The Climate Index has a bimodal distribution, with the range from 1.00 to 1.25 having a 75% probability, and the range from 1.50 to 2.25 having a 25% probability. Because implementation of the Climate Index leads to radionuclide releases through the Culebra that are orders of magnitude lower than the regulatory limits, the effects of flow between the Culebra and deeper units through abandoned boreholes can be screened out on the basis of low consequence.

SCR-5.2.1.9.3.4 Connections Between the Culebra and Shallower Units

Abandoned boreholes could also provide interconnections for long-term fluid flow between shallow units (overlying the Salado). Abandoned boreholes could provide pathways for downward flow of water from the Dewey Lake and/or Magenta to the Culebra because the Culebra hydraulic head is lower than the hydraulic heads of these units. Magenta freshwater heads are as much as 45 m (148 ft) higher than Culebra freshwater heads. Because the Culebra is generally at least one order of magnitude more transmissive than the Magenta at any location, a connection between the Magenta and Culebra would cause proportionally more drawdown in the Magenta head than rise in the Culebra head. For example, for a one-order-of-magnitude difference in transmissivity and a 45-m (148-ft) difference in head, the Magenta head would decrease by approximately 40 m (131 ft) while the Culebra head increased by 5 m (16 ft). This head increase in the Culebra would also be a localized effect, decreasing with radial distance from the leaking borehole. The primary flow direction in the Culebra across the WIPP site is from north to south, with the Culebra head decreasing by approximately 20 m (66 ft) across this distance. A 5-m (16-ft) increase in Culebra head at the northern WIPP boundary would, therefore, increase gradients by at most 25%.

The Dewey Lake freshwater head at the WQSP-6 pad is 55 m (180 ft) higher than the Culebra freshwater head. Leakage from the Dewey Lake could have a greater effect on Culebra head than leakage from the Magenta if the difference in transmissivity between the Dewey Lake and Culebra observed at the WQSP-6 pad, where the Dewey Lake is two orders of magnitude more transmissive than the Culebra (Beauheim and Ruskauff 1998), persists over a wide region. However, the saturated, highly transmissive zone in the Dewey Lake has only been observed south of the WIPP disposal panels. A connection between the Dewey Lake and the Culebra south of the panels would tend to decrease the north-south gradient in the Culebra across the site, not increase it.

In any case, leakage of water from overlying units into the Culebra could not increase Culebra heads and gradients as much as might result from climate change, discussed above. Because implementation of the Climate Index leads to radionuclide releases through the Culebra that are orders of magnitude lower than the regulatory limits, the effects of flow between the Culebra and shallower units through abandoned boreholes can be screened out on the basis of low consequence.

SCR-5.2.1.9.3.5 Changes in Fluid Density Resulting from Flow Through Abandoned Boreholes

Leakage from historical, current, and near-future abandoned boreholes that penetrate pressurized brine pockets in the Castile could give rise to fluid density changes in affected units. Wilmot and Galson (Wilmot and Galson 1996) showed that brine density changes in the Culebra resulting from leakage through an abandoned borehole would not have a significant effect on the Culebra flow field. A localized increase in fluid density in the Culebra resulting from leakage from an abandoned borehole would rotate the flow vector towards the downdip direction (towards the east). A comparison of the relative magnitudes of the freshwater head gradient and the gravitational gradient, based on an analysis similar to that presented in Section SCR-5.2.1.6 (FEPs H27, H28, and H29), shows that the density effect is of low consequence to the performance of the disposal system.

SCR-5.2.1.9.3.6 Future Human EPs

The EPA provides criteria for analysis of the consequences of future drilling events in section 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete, the borehole is plugged according to current practice in the Delaware Basin (see the CCA, Chapter 6.0, Section 6.4.7.2, and Camphouse 2013a). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.9.3.7 Hydraulic Effects of Flow Through Abandoned Boreholes

A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. Long-term natural borehole fluid flow through such a borehole is accounted for in PA calculations (see the CCA, Chapter 6.0, Section 6.4.8).

Deep, abandoned boreholes that intersect the Salado interbeds near the waste disposal panels could provide pathways for long-term radionuclide transport from the waste panels to the land surface or to overlying units. The potential significance of such events were assessed by the

WIPP PA Department (1991, B-26 to B-27), which examined single-phase flow and transport between the waste panels and a borehole intersecting MB 139 outside the DRZ. The analysis assumed an in situ pressure of 11 MPa in MB 139, a borehole pressure of 6.5 MPa (975 psi) (hydrostatic) at MB 139, and a constant pressure of 18 MPa (2,700 psi) as a source term in the waste panels representing gas generation. Also, MB 139 was assigned a permeability of approximately 3×10^{-20} m^2 (3.2×10^{-19} ft^2) and a porosity of 0.01%. The disturbed zone was assumed to exist in MB 139 directly beneath the repository only and was assigned a permeability of 1.0×10^{-17} m^2 (1.1×10^{-16} ft^2) and a porosity of 0.055%. Results showed that the rate of flow through a borehole located just 0.25 m (0.8 ft) outside the DRZ would be more than two orders of magnitude less than the rate of flow through a borehole located within the DRZ because of the contrast in permeability. Thus, any releases of radionuclides to the accessible environment through deep boreholes that do not intersect waste panels would be insignificant compared to the releases that would result from transport through boreholes that intersect waste panels. Thus, radionuclide transport through deep boreholes that do not intersect waste panels has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.9.3.8 Fluid Flow and Radionuclide Transport in the Culebra

Fluid flow and radionuclide transport within the Culebra could be affected if future boreholes result in hydraulic connections between the Culebra and either deeper or shallower units. Over the 10,000-yr regulatory period, a large number of deep boreholes could be drilled within and around the controlled area (see the CCA, Chapter 6.0, Section 6.4.12.2). The effects on the performance of the disposal system of long-term hydraulic connections between the Culebra and deeper or shallower units would be the same as those discussed above for historic, current, and near-future conditions. Thus, the effects of flow between the Culebra and deeper or shallower units through abandoned future boreholes can be screened out on the basis of low consequence.

SCR-5.2.1.9.3.9 Changes in Fluid Density Resulting from Flow Through Abandoned Boreholes

A future borehole that intersects a pressurized brine reservoir in the Castile could also provide a source for brine flow to the Culebra in the event of borehole casing leakage, with a consequent localized increase in fluid density in the Culebra. The effect of such a change in fluid density would be to increase any density-driven component of groundwater flow. If the downdip direction, along which the density-driven component would be directed, is different from the direction of the groundwater pressure gradient, there would be a slight rotation of the flow vector towards the downdip direction. The groundwater modeling presented by Davies (Davies 1989, p. 50) indicates that a borehole that intersects a pressurized brine pocket and causes a localized increase in fluid density in the Culebra above the waste panels would result in a rotation of the flow vector slightly towards the east. However, the magnitude of this effect would be small in comparison to the magnitude of the pressure gradient (see screening argument for FEPs H27, H28, and H29, Section SCR-5.2.1.6, where this effect is screened out on the basis of low consequence).

SCR-5.2.1.10 **FEP Number:** H32
FEP Title: *Waste-Induced Borehole Flow*

SCR-5.2.1.10.1 Screening Decision: SO-R (HCN)
DP (Future)

Waste-induced flow through boreholes drilled in the near future has been eliminated from PA calculations on regulatory grounds. *Waste-Induced Borehole Flow* through a future borehole that intersects a waste panel is accounted for in PA calculations.

SCR-5.2.1.10.2 Summary of New Information

Probabilities for the various borehole types used in PA have been updated based on information gathered by the Delaware Basin Monitoring Program. These updated probabilities do not impact or change the screening arguments or decisions, but are incorporated into PA in an effort to reflect current technologies and methods used in industry. These PA parameters are described in Camphouse (Camphouse 2013a).

SCR-5.2.1.10.3 Screening Argument

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

Continued resource exploration and production in the near future will result in the occurrence of many more abandoned boreholes in the vicinity of the controlled area. Institutional controls will prevent drilling (other than that associated with the WIPP development) from taking place within the controlled area in the near future. Therefore, no boreholes will intersect the waste disposal region in the near future, and waste-induced borehole flow in the near future has been eliminated from PA calculations on regulatory grounds.

SCR-5.2.1.10.3.1 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in section 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete, the borehole is plugged according to current practice in the Delaware Basin (see the CCA, Chapter 6.0, Section 6.4.7.2 and Camphouse 2013a). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.10.3.2 Hydraulic Effects of Flow Through Abandoned Boreholes

An abandoned future borehole that intersects a waste panel could provide a connection for contaminant transport away from the repository horizon. If the borehole has degraded casing and/or plugs, and the fluid pressure within the waste panel is sufficient, radionuclides could be transported to the land surface. Additionally, if brine flows through the borehole to overlying units, such as the Culebra, it may carry dissolved and colloidal actinides that can be transported laterally to the accessible environment by natural groundwater flow in the overlying units. Long-term waste-induced borehole flow is accounted for in PA calculations (see Appendix PA-2014, Section PA-2.1.2.5).

SCR-5.2.1.11 FEP Number: H34
FEP Title: *Borehole-Induced Solution and Subsidence*

SCR-5.2.1.11.1 Screening Decision: SO-C (HCN)
SO-C (Future)

The effects of *Borehole-Induced Solution and Subsidence* associated with existing, near-future, and future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.11.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.11.3 Screening Argument

Potentially, boreholes could provide pathways for surface-derived water or groundwater to percolate through low-permeability strata and into formations containing soluble minerals. Large-scale dissolution through this mechanism could lead to subsidence and to changes in groundwater flow patterns. Also, fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation.

SCR-5.2.1.11.3.1 Historical, Current, and Near-Future Human EPs

SCR-5.2.1.11.3.1.1 Borehole-Induced Solution and Subsidence
During the period covered by HCN FEPs, drilling within the land withdrawn for the WIPP will be controlled, and boreholes will be plugged according to existing regulations. Under these circumstances and during this time period, borehole-induced solution and subsidence at the WIPP is eliminated from PA calculations on the basis of no consequence to the disposal system.

Outside the area withdrawn for the WIPP, drilling has been regulated, but conditions of historical and existing boreholes are highly variable. Borehole-induced solution and subsidence may occur in these areas, although it is expected to be limited and should not affect the disposal system, as discussed in the following paragraphs.

Three features are required for significant borehole-induced solution and subsidence to occur: a borehole, an energy gradient to drive unsaturated (with respect to halite) water through the evaporite-bearing formations, and a conduit to allow migration of brine away from the site of dissolution. Without these features, minor amounts of halite might be dissolved in the immediate vicinity of a borehole, but percolating water would become saturated with respect to halite and stagnant in the bottom of the drillhole, preventing further dissolution.

At, and in the vicinity of the WIPP site, drillholes penetrating into but not through the evaporite-bearing formations have little potential for dissolution. Brines coming from the Salado and Castile, for example, have high total dissolved solids and are likely to precipitate halite, not dissolve more halite during passage through the borehole. Water infiltrating from the surface or near-surface units may not be saturated with halite. For drillholes with a total depth in halite-bearing formations, there is little potential for dissolution because the halite-bearing units have very low permeability and provide little outlet for the brine created as the infiltrating water fills the drillhole. ERDA-9 is the deepest drillhole in the immediate vicinity of the waste panels at the WIPP; the bottom of the drillhole is in the uppermost Castile, with no known outlet for brine at the bottom.

Drillholes penetrating through the evaporite-bearing formations provide possible pathways for circulation of water. Underlying units in the vicinity of the WIPP site with sufficient potentiometric levels or pressures to reach or move upward through the halite units generally have one of two characteristics: (1) high-salinity brines, which limit or eliminate the potential for dissolution of evaporites, or (2) are gas producers. Wood et al. (Wood et al. 1982) analyzed natural processes of dissolution of the evaporites by water from the underlying Bell Canyon. They concluded that brine removal in the Bell Canyon is slow, limiting the movement of dissolution fronts or the creation of natural collapse features. Existing drillholes that are within the boundaries of the withdrawn land and also penetrate through the evaporites are not located in the immediate vicinity of the waste panels or WIPP workings.

There are three examples in the region that appear to demonstrate the process for borehole-induced solution and subsidence, but the geohydrologic setting and drillhole completions differ from those at or near the WIPP.

An example of borehole-induced solution and subsidence occurred in 1980 about 160 km (100 mi) southeast of the WIPP site (outside the Delaware Basin) at the Wink Sink (Baumgardner et al. 1982; Johnson 1989), where percolation of shallow groundwater through abandoned boreholes, dissolution of the Salado, and subsidence of overlying units led to a surface collapse feature 110 m (360 ft) in width and 34 m (110 ft) deep. At the Wink Sink, the Salado is underlain by the Tansill, Yates, and Capitan Formations, which contain vugs and solution cavities through which brine could migrate. Also, the hydraulic head of the Santa Rosa (the uppermost aquifer) is greater than those of the deep aquifers (Tansill, Yates, and Capitan), suggesting downward flow if a connection were established. A second sink (Wink Sink 2) formed in May 2002, near the earlier sink (Johnson et al. 2003). Its origin is similar to the earlier sink. By February 2003, Wink Sink 2 had enlarged by surface collapse to a length of about 305 m (1,000 ft) and a width of about 198 m (650 ft).

A similar, though smaller, surface collapse occurred in 1998 northwest of Jal, New Mexico (Powers 2000). The most likely cause of collapse appears to be dissolution of Rustler, and possibly Salado, halite as relatively low salinity water from the Capitan Reef circulated through breaks in the casing of a deep water supply well. Much of the annulus behind the casing through the evaporite section was uncemented, and work in the well at one time indicated bent and ruptured casing. The surface collapse occurred quickly, and the sink was initially about 23 m (75 ft) across and a little more than 30 m (100 ft) deep. By 2001, the surface diameter was about 37 m (120 ft), and the sink was filled with collapse debris to about 18 m (60 ft) below the ground level (Powers, in press).

The sinkholes near Wink, Texas and Jal, New Mexico, occurred above the Capitan Reef (which is by definition outside the Delaware Basin), and the low-salinity water and relatively high potentiometric levels of the Capitan Reef appear to be integral parts of the process that formed these sinkholes. They are reviewed as examples of the process of evaporite dissolution and subsidence related to circulation in drillholes. Nevertheless, the factors of significant low salinity water and high potentiometric levels in units below the evaporites do not appear to apply at the WIPP site.

Beauheim (Beauheim 1986) considered the direction of natural fluid flow through boreholes in the vicinity of the WIPP. Beauheim (Beauheim 1986, p. 72) examined hydraulic heads measured using drill stem tests in the Bell Canyon and the Culebra at well DOE-2 and concluded that the direction of flow in a cased borehole open only to the Bell Canyon and the Culebra would be upward. Bell Canyon waters in the vicinity of the WIPP site are saline brines (e.g., Lambert 1978; Beauheim et al. 1983; Mercer et al. 1987), limiting the potential for dissolution of the overlying evaporites. However, dissolution of halite in the Castile and the Salado would increase the relative density of the fluid in an open borehole, causing a reduction in the rate of upward flow. The direction of borehole fluid flow could potentially reverse, but such a flow could be sustained only if sufficient driving pressure, porosity, and permeability exist for fluid to flow laterally within the Bell Canyon. A further potential sink for Salado-derived brine is the Capitan Limestone. However, the subsurface extent of the Capitan Reef is approximately 16 km (10 mi) from the WIPP at its closest point, and this unit will not provide a sink for brine derived from boreholes in the vicinity of the controlled area. A similar screening argument is made for natural deep dissolution in the vicinity of the WIPP (see N16 and N18, Section SCR-4.1.5.1 and Section SCR-4.1.5.2).

The effects of borehole-induced solution and subsidence through a waste panel are considered below. The principal effects of borehole-induced solution and subsidence in the remaining parts of the disposal system should be to change the hydraulic properties of the Culebra and other rocks in the system. The features are local (limited lateral dimensions) and commonly nearly circular. If subsidence occurs along the expected travel path and the transmissivity of the Culebra is increased, as in the calculations conducted by Wallace (Wallace 1996c), the travel times should increase. If the transmissivity along the expected flow path decreased locally as a result of such a feature, the flow path should be lengthened by travel around the feature. Thus, the effects of borehole-induced solution and subsidence around existing abandoned boreholes, and boreholes drilled and abandoned in the near-future, have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.11.3.2 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in section 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see Appendix PA-2014, Section PA-2.1.2.5). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.11.3.2.1 Borehole-Induced Solution and Subsidence

Future boreholes that do not intersect the WIPP excavation do not differ in long-term behavior or consequences from existing boreholes, and can be eliminated from PA on the basis of low consequence to the performance of the disposal system.

The condition of more apparent concern is a future borehole that intersects the WIPP excavation. Seals and casings are assumed to degrade, connecting the excavation to various units. For a drillhole intersecting the excavation, but not connecting to a brine reservoir or to formations below the evaporites, downward flow is limited by the open volume of the disposal room(s), which is dependent with time, gas generation, or brine inflow to the disposal system from the Salado.

Maximum dissolution, and maximum increase in borehole diameter, will occur at the top of the Salado; dissolution will decrease with depth as the percolating water becomes salt saturated. Eventually, degraded casing and concrete plug products, clays, and other materials will fill the borehole. Long-term flow through a borehole that intersects a waste panel is accounted for in DP calculations by assuming that the borehole is eventually filled by such materials, which have the properties of a silty sand (see Appendix PA-2014, Section PA-2.1.2.5). However, these calculations assume that the borehole diameter does not increase with time. Under the conditions assumed in the CCA for an E2 drilling event at 1,000 yrs, about 1,000 m^3 (35,316 ft^3) would be dissolved from the lower Rustler and upper Salado. If the dissolved area is approximately cylindrical or conical around the borehole, and the collapse/subsidence propagates upward as occurred in breccia pipes (e.g., Snyder and Gard 1982), the diameter of the collapsed or subsided area through the Culebra and other units would be a few tens of meters across. Changes in hydraulic parameters for this small zone should slow travel times for any hypothesized radionuclide release, as discussed for HCN occurrences. This does not change the argument for low consequence due to borehole-induced solution and subsidence for these circumstances.

If a drillhole through a waste panel and into deeper evaporites intercepts a Castile brine reservoir, the brine has little or no capability of dissolving additional halite. The Castile brine flow is considered elsewhere as part of DP. There is, however, no *Borehole-Induced Solution and Subsidence* under this circumstance, and therefore there is no effect on performance because of this EP.

If a borehole intercepts a waste panel and also interconnects with formations below the evaporite section, fluid flow up or down is determined by several conditions and may change over a period of time (e.g., as dissolution increases the fluid density in the borehole). Fluid flow downward is not a concern for performance, as fluid velocities in units such as the Bell Canyon are slow and should not be of concern for performance (Wilson et al. 1996). As with boreholes considered for HCN, the local change in hydraulic parameters, if it occurs along the expected flow path, would be expected to cause little change in travel time and should increase the travel time.

In summary, the effects of borehole-induced solution and subsidence around future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.12 **FEP Number:** H35
FEP Title: *Borehole-Induced Mineralization*

SCR-5.2.1.12.1 Screening Decision: SO-C (HCN)
SO-C (Future)

The effects of *Borehole-Induced Mineralization*, associated with existing, near-future, and future abandoned boreholes, have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.12.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.12.3 Screening Argument

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units, such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

Potentially, boreholes could provide pathways for surface-derived water or groundwater to percolate through low-permeability strata and into formations containing soluble minerals. Large-scale dissolution through this mechanism could lead to subsidence and to changes in groundwater flow patterns. Also, fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation.

SCR-5.2.1.12.3.1 Borehole-Induced Mineralization

Fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation. For example:

- Limited calcite precipitation may occur as the waters mix in the Culebra immediately surrounding the borehole, and calcite dissolution may occur as the brines migrate away from the borehole as a result of variations in water chemistry along the flow path.

- Gypsum may be dissolved as the waters mix in the Culebra immediately surrounding the borehole but may precipitate as the waters migrate through the Culebra.

The effects of these mass transfer processes on groundwater flow depend on the original permeability structure of the Culebra rocks and the location of the mass transfer. The volumes of minerals that may precipitate or dissolve in the Culebra as a result of the injection of Castile or Salado brine through a borehole will not affect the existing spatial variability in the permeability field significantly.

Predicted radionuclide transport rates in the Culebra assume that the dolomite matrix is diffusively accessed by the contaminants. The possible inhibition of matrix diffusion by secondary mineral precipitation on fracture walls as a result of mixing between brines and Culebra porewater was addressed by Wang (Wang 1998). Wang showed that the volume of secondary minerals precipitated because of this mechanism was too small to significantly affect matrix porosity and accessibility.

Consequently, the effects of borehole-induced mineralization on permeability and groundwater flow within the Culebra, as a result of brines introduced via any existing abandoned boreholes and boreholes drilled and abandoned in the near future, have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.12.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in section 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see DOE 2012, Section 2.7, and Appendix PA-2014, Section PA 2.1.2.5). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.12.4.1 Borehole-Induced Mineralization

Fluid flow between hydraulically conductive horizons through a future borehole may result in changes in permeability in the affected units through mineral precipitation. However, the effects of mineral precipitation as a result of flow through a future borehole in the controlled area will be similar to the effects of mineral precipitation as a result of flow through an existing or near-future borehole (see FEP H32, Section SCR-5.2.1.10). Thus, borehole-induced mineralization associated with flow through a future borehole has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.13 **FEP Number:** H36
FEP Title: *Borehole-Induced Geochemical Changes*

SCR-5.2.1.13.1 Screening Decision: UP (HCN)
DP (Future)
SO-C for units other than the Culebra

Geochemical changes that occur inside the controlled area as a result of long-term flow associated with HCN and future abandoned boreholes are accounted for in PA calculations.

SCR-5.2.1.13.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.1.13.3 Screening Argument

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

SCR-5.2.1.13.3.1 Geochemical Effects of Borehole Flow

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area, or if they occur as a result of flow through existing boreholes within the controlled area through their effects on colloid transport and sorption.

The contents of the waste disposal panels provide the main source of colloids in the disposal system. Thus, consistent with the discussion in Section SCR-5.2.1.4 (*Borehole-Induced Geochemical Changes* [H24]), colloid transport as a result of flow through existing and near-future abandoned boreholes has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

As discussed in H24, sorption within the Culebra is accounted for in PA calculations. The sorption model used accounts for the effects of changes in sorption in the Culebra as a result of flow through existing and near-future abandoned boreholes.

Consistent with the screening discussion in Section SCR-5.2.1.4, the effects of changes in sorption in the Dewey Lake inside the controlled area as a result of flow through existing and near-future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-5.2.1.13.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in section 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see DOE 2012, Section 2.7, and Appendix PA-2014, Section PA-3.7). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.13.4.1 Geochemical Effects of Flow Through Abandoned Boreholes

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units, such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units through their effects on colloid transport and sorption.

The waste disposal panels provide the main source of colloids in the disposal system. Colloid transport within the Culebra as a result of long-term flow associated with future abandoned boreholes that intersect the waste disposal region are accounted for in PA calculations, as described in the CCA, Chapter 6.0, Section 6.4.3.6 and Section 6.4.6.2.1. Consistent with the discussion in Section SCR-5.2.1.4, colloid transport as a result of flow through future abandoned boreholes that do not intersect the waste disposal region has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The Culebra is the most transmissive unit in the disposal system and it is the most likely unit through which significant radionuclide transport could occur. Therefore, colloid transport in units other than the Culebra, as a result of flow through future abandoned boreholes, has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR-5.2.1.4, sorption within the Culebra is accounted for in PA calculations. The sorption model accounts for the effects of changes in sorption in the Culebra as a result of flow through future abandoned boreholes.

Consistent with the screening discussion in Section SCR-5.2.1.4, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of flow through future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-5.2.2 Excavation-Induced Flow

SCR-5.2.2.1 **FEP Number:** H37
FEP Title: *Changes in Groundwater Flow Due to Mining*

SCR-5.2.2.1.1 Screening Decision: UP (HCN)
DP (Future)

Changes in Groundwater Flow due to *Mining* (HCN and future) are accounted for in PA calculations.

SCR-5.2.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.2.1.3 Screening Argument

Excavation activities may result in hydrological disturbances of the disposal system. Subsidence associated with excavations may affect groundwater flow patterns through increased hydraulic conductivity within and between units. Fluid flow associated with excavation activities may also result in changes in brine density and geochemistry in the disposal system.

SCR-5.2.2.1.3.1 Historical, Current, and Near-Future Human EPs

Currently, potash mining is the only excavation activity currently taking place in the vicinity of the WIPP that could affect hydrogeological or geochemical conditions in the disposal system. Potash is mined in the region east of Carlsbad and up to 5 km (3.1 mi) from the boundaries of the controlled area. Mining of the McNutt Potash Zone in the Salado is expected to continue in the vicinity of the WIPP (see the CCA, Chapter 2.0, Section 2.3.1.1): the DOE assumes that all economically recoverable potash in the vicinity of the WIPP (outside the controlled area) will be extracted in the near future.

SCR-5.2.2.1.3.2 Hydrogeological Effects of Mining

Potash mining in the Delaware Basin typically involves constructing vertical shafts to the elevation of the ore zone and then extracting the minerals in an excavation that follows the trend of the ore body. Potash has been extracted using conventional room-and-pillar mining, secondary mining where pillars are removed, and modified long-wall mining methods. Mining techniques used include drilling and blasting (used for mining langbeinite) and continuous mining (commonly used for mining sylvite). The DOE (Westinghouse 1994, pp. 2-17 to 2-19) reported investigations of subsidence associated with potash mining operations located near the WIPP. The reported maximum total subsidence at potash mines is about 1.5 m (5 ft), representing up to 66% of initial excavation height, with an observed angle of draw from the vertical at the edge of the excavation of 58 degrees. The DOE (Westinghouse 1994 pp. 2-22 to 2-23) found no evidence that subsidence over local potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the surface. However, subsidence and fracturing associated with mining in the McNutt in the vicinity of the WIPP may allow increased recharge to the Rustler units and affect the lateral hydraulic conductivity of overlying units, such as the Culebra, which could influence the direction and magnitude of fluid flow within the disposal system. Such changes in groundwater flow due to mining are accounted for in calculations of UP of the disposal system. The effects of any increased recharge that may be occurring are, in effect, included by using the hydraulic heads measured to calibrate Culebra transmissivity fields (T-fields) and calculate transport through those fields (Appendix TFIELD-2014).

Potash mining, and the associated processing outside the controlled area, have changed fluid densities within the Culebra, as demonstrated by the areas of higher densities around boreholes WIPP-27 and WIPP-29 (Davies 1989, p. 43). Transient groundwater flow calculations (Davies 1989, pp. 77–81) show that brine density variations to the west of the WIPP site caused by historical and current potash processing operations will not persist because the rate of groundwater flow in this area is fast enough to flush the high-density groundwaters to the Pecos River. These calculations also show that accounting for the existing brine density variations in the region east of the WIPP site, where hydraulic conductivities are low, would have little effect on the direction or rate of groundwater flow. Therefore, changes in fluid densities from historical and current human EPs have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

The distribution of existing leases and potash grades suggests that near-future mining will take place to the north, west, and south of the controlled area (see the CCA, Appendix DEL). A localized increase in fluid density in the Culebra, in the mined region or elsewhere outside the controlled area, would rotate the flow vector towards the downdip direction (towards the east). A comparison of the relative magnitudes of the pressure gradient and the density gradient (based on an analysis identical to that presented for fluid leakage to the Culebra through boreholes) shows that the density effect is of low consequence to the performance of the disposal system.

SCR-5.2.2.1.4 Future Human EPs

Consistent with section 194.32(b), consideration of future mining may be limited to potash mining within the disposal system. Within the controlled area, the McNutt provides the only potash of appropriate quality. The extent of possible future potash mining within the controlled area is discussed in the CCA, Chapter 2.0, Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in section 194.32(b): the effects of future mining may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system. Thus, consistent with section 194.32(b), changes in groundwater flow due to mining within the controlled area are accounted for in calculations of the DP of the disposal system (see the CCA, Chapter 6.0, Section 6.4.6.2.3).

SCR-5.2.2.2 **FEP Number:** H38
FEP Title: *Changes in Geochemistry Due to Mining*

SCR-5.2.2.2.1 Screening Decision: SO-C (HCN)
SO-R (Future)

Changes in Geochemistry due to Mining (HCN) have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Changes in Geochemistry due to Mining* have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.2.2.3 Screening Argument

SCR-5.2.2.2.3.1 Historical, Current, and Near-Future Human EPs

Potash mining is the only excavation activity currently taking place in the vicinity of the WIPP that could affect hydrogeological or geochemical conditions in the disposal system. Potash is mined in the region east of Carlsbad and up to 5 km (1.5 mi) from the boundaries of the controlled area. Mining of the McNutt in the Salado is expected to continue in the vicinity of the WIPP (see the CCA, Chapter 2.0, Section 2.3.1.1): the DOE assumes that all economically recoverable potash in the vicinity of the WIPP (outside the controlled area) will be extracted in the near future.

SCR-5.2.2.2.3.2 Geochemical Effects of Mining

Fluid flow associated with excavation activities may result in geochemical disturbances of the disposal system. Some waters from the Culebra reflect the influence of current potash mining, having elevated potassium to sodium ratios. However, potash mining has had no significant effect on the geochemical characteristics of the disposal system. Solution mining, which involves the injection of freshwater to dissolve the ore body, can be used for extracting sylvite. The impact on the WIPP of neighboring potash mines was examined in greater detail by D’Appolonia (D’Appolonia 1982). D’Appolonia noted that attempts to solution mine sylvite in the Delaware Basin failed because of low ore grade, thinness of the ore beds, and problems with heating and pumping injection water. See discussion in Section SCR-5.1.2.1 (*Conventional Underground Potash Mining* [H13]). Thus, changes in geochemistry due to mining (HCN) have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.2.2.3.3 Future Human EPs

Consistent with section 194.32(b), consideration of future mining may be limited to potash mining within the disposal system. Within the controlled area, the McNutt provides the only potash of appropriate quality. The extent of possible future potash mining within the controlled area is discussed in the CCA, Chapter 2.0, Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in section 194.32(b): the effects of future mining may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system. Thus, consistent with section 194.32(b), changes in groundwater flow as a result of mining within the controlled area are accounted for in calculations of the DP of the disposal system (see the CCA, Chapter 6.0, Section 6.4.6.2.3). Other potential effects, such as changes in geochemistry due to mining, have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.2.3 **FEP Number** H58
FEP Title: *Solution Mining for Potash*

SCR-5.2.2.3.1 Screening Decision: SO-R (HCN)
SO-R (Future)

HCN and future *Solution Mining for Potash* has been eliminated from PA calculations on regulatory grounds. HCN and future solution mining for other resources has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.2.3.2 Summary of New Information

The prospect of using solution-mining techniques for extracting potash has been identified and considered in the region since the mid-1990s. After a lengthy planning and permitting period, Intrepid Potash, Inc., recently began flooding the abandoned mine workings of the old Eddy Potash mine in an effort to extract residual potash (sylvite) from the mine pillars. This potash is unrecoverable through conventional methods due to mine stability issues as discussed below. The extent of solutioning will be north of the Delaware Basin boundary, and is therefore beyond the region of interest for the WIPP Project. The initiation of this project does not invalidate current screening arguments and decisions, because the actual solution activity is outside the Delaware Basin. The screening argument has been updated with details of this new project and additional justification for the current screening decision.

SCR-5.2.2.3.3 Screening Argument

The potash reserves evaluated by Griswold and Griswold (Griswold and Griswold 1999) and New Mexico Bureau of Mines and Mineral Resources (New Mexico Bureau of Mines and Mineral Resources 1995) at the WIPP are of economic importance in only two ore zones; the 4th and the 10th contain two minerals of economic importance, langbeinite and sylvite. The ore in the 10th ore zone is primarily sylvite with some langbeinite and the ore in the 4th zone is langbeinite with some sylvite. Langbeinite falls between gypsum and polyhalite in solubility and dissolves at a rate 1000 times slower than sylvite (Heyn 1997). Halite, the predominate gangue mineral present, is much more soluble than the langbeinite. Because of the insolubility of langbeinite, sylvite is the only potash ore in the WIPP vicinity that could be mined using a solution mining process. Mining for sylvite by solutioning would cause the langbeinite to be lost because conventional mining could not be done in conjunction with a solution mining process.

Typically, solution mining is used for potash:

When deposits are at depths in excess of 914 m (3,000 ft) and rock temperatures are high, or are geologically too complex to mine profitably using conventional underground mining techniques

To recover the potash pillars at the end of a mine's life

When a mine is unintentionally flooded with waters from underlying or overlying rock strata and conventional mining is no longer feasible

Communiqués with IMC Global (Heyn 1997; Prichard 2003) indicated that rock temperature is critical to the success of a solution-mining endeavor. Mosaic Potash's (previously IMC Global) solution mines in Michigan and Saskatchewan are at depths of around 914 m (3,000 ft) or greater, at which rock temperatures are higher. The ore zones at the WIPP are shallow, at depths of 457 to 549 m (1,500 to 1,800 ft), with fairly cool rock temperatures. Prichard (Prichard 2003) states that solution mining is energy intensive and the cool temperature of the rock would add to the energy costs. In addition, variable concentrations of confounding minerals (such as kainite and leonite) will cause problems with the brine chemistry.

Douglas W. Heyn (chief chemist of IMC Kalium) provided written testimony to the EPA related to the Agency's rulemaking activities on the CCA. Heyn concluded that "the rational choice for extracting WIPP potash ore reserves would be by conventional room and pillar mechanical means" (Heyn 1997). It is the opinion of IMC Global that no company will ever attempt solution mining of the ores in or near the WIPP (Heyn 1997; Prichard 2003).

The impact on the WIPP of neighboring potash mines and the possible effects of solution mining for potash or other evaporite minerals were examined in detail by D'Appolonia (D'Appolonia 1982). According to D'Appolonia (D'Appolonia 1982), and in agreement with Heyn (Heyn 1997) of IMC Global, Inc., solution mining of langbeinite is not technically feasible because the ore is less soluble than the surrounding evaporite minerals. Serious technical and economic obstacles exist that render solution mining for potash very unlikely in the immediate vicinity of the WIPP. Expectedly, no operational example of this technology exists within the Delaware Basin; that is, solution mining for potash in not considered a current practice in the area. For this reason, consideration of solution mining on the disposal system in the future may be excluded on regulatory grounds. For example, the EPA stated in their Response to Comments, Section 8, Issue GG (EPA 1998d):

> …However, the Agency emphasizes that, in accordance with the WIPP compliance criteria, solution mining does not need to be included in the PA. As previously discussed, potash solution mining is not an ongoing activity in the Delaware Basin. Section 194.32(b) of the rule limits assessment of mining effects to excavation mining. Thus the solution mining scenarios proposed are excluded on regulatory grounds after repository closure. Prior to or soon after disposal, solution mining is an activity that could be considered under Section 194.32(c). However, DOE found that potash solution mining is not an ongoing activity in the Delaware Basin; and one pilot project examining solution mining in the Basin is not substantive evidence that such mining is expected to occur in the near future. (Even if mining were assumed to occur in the near future, the proposed scenarios would not be possible because, even though solution mining might occur, there would be no intruding borehole to provide a pathway into the repository: active institutional controls would preclude such drilling during the first 100 years after disposal.) Furthermore, Section 194.33(d) states that PA need not analyze the effects of techniques used for resource recovery (e.g. solution mining) after a borehole is drilled in the future.

Conventional mining activities will continue to be incorporated into the WIPP PA as directed by the EPA CAG (U.S. EPA 1996b). Because the potash mines in the vicinity of the WIPP are in their mature (declining) stages of production, solution mining may be used in the future for extraction of remaining pillars, as is being done in the Intrepid Potash, Inc. project just outside the Delaware Basin. Nonetheless, at the time of this FEP reassessment, this technology is not being employed within the Delaware Basin and a screening based on the future states assumption at section 194.25(a) is appropriate for this mining technique at this time. While a regulatory screening (SO-R) is currently appropriate, if a potash solution mining project were to exist within the vicinity of the WIPP (within the Delaware Basin), the DOE has effectively argued that the consequences of such activity would be of low consequence, and addressed by conventional mining FEPs. In a response to the Environmental Evaluation Group comment, the DOE effectively argued that, "If solution mining for potash were undertaken in the vicinity of the WIPP it could result in subsidence. However, performance assessment calculations already assume that widespread subsidence will occur as a result of potash mining in the near future. The assumed extent of subsidence and its effects on the hydraulic conductivity of Culebra are independent of the mining methods used (underground excavation or solution mining)." (U.S. EPA 1998d).

SCR-5.2.2.4 FEP Number: H59
FEP Title: *Solution Mining for Other Resources*

SCR-5.2.2.4.1 Screening Decision: SO-C (HCN)
SO-C (Future)

HCN and future *Solution Mining for Other Resources* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.2.4.2 Summary of New Information

Brine well information provided in Table SCR-2 has been updated based on new information from the DBDSP (U.S. DOE 2012). The CRA-2009 reported 12 active brine wells within the Delaware Basin. For the CRA-2014 the DBDSP again reports 12 active brine wells, although they are not the same 12 as reported in 2009. Two previously active wells have been taken out of service and plugged and abandoned. Alternatively, there have been two new brine wells put into service during this period, leaving the total active brine wells at 12. Updated information is also provided that describes brine well collapses in southeast New Mexico.

SCR-5.2.2.4.3 Screening Argument

Brine wells (solution mining for brine) exist within the Delaware Basin, although none within the vicinity of the WIPP. Sulfur extraction using the Frasch process began in 1969 and continued for three decades at the Culberson County Rustler Springs mine near Orla, Texas. Solution mining for the purposes of creating a storage cavity has not occurred within the New Mexico portion of the Delaware Basin.

SCR-5.2.2.4.4 Solution Mining for Brine

Oil and gas reserves in the Delaware Basin are located in structures within the Delaware Mountain Group and lower stratigraphic units. Boreholes drilled to reach these horizons pass through the Salado and Castile that comprise thick halite and other evaporite units. To avoid dissolution of the halite units during drilling and prior to casing of the borehole, the fluid used for lubrication, rotating the drilling-bit cutters, and transporting cuttings (drilling mud) must be saturated with respect to halite. Most oil- and gas-field drilling operations in the Delaware Basin therefore use saturated brine (10 to 10.5 pounds per gallon [lb/gal]) as a drilling fluid until reaching the Bell Canyon, where intermediate casing is set.

One method of providing saturated brine for drilling operations is solution mining, whereby fresh water is pumped into the Salado, allowed to reach saturation with respect to halite, and then recovered. This manufactured brine is then transported to the drilling site by water tanker.

Two principal techniques are used for solution mining: single-borehole operations and doublet or two-borehole operations.

Table SCR-2. Delaware Basin Brine Well Status

County	Location	API No.	Well Name and No.	Operator	CRA-2009 Status	CRA-2014 Status†
Eddy	22S-26E-36	3001521842	City of Carlsbad #WS-1	Key Energy Services	Active Brine Well	**Plugged Brine Well**
Eddy	22S-27E-03	3001520331	Tracy #3	Ray Westall	Plugged Brine Well	Plugged Brine Well
Eddy	22S-27E-17	3001522574	Eugenie #WS-1	I & W Inc	Active Brine Well	**Plugged Brine Well**
Eddy	22S-27E-17	3001523031	Eugenie #WS-2	I & W Inc	Plugged Brine Well	Plugged Brine Well
Eddy	22S-27E-23	3001528083	Dunaway #1	Mesquite SWD, Inc.	Active Brine Well	Active Brine Well
Eddy	22S-27E-23	3001538084	Dunaway #2	Mesquite SWD, Inc.	--	**Active Brine Well**
Loving	Blk 29-03	4230110142	Lineberry Brine Station #1	Chance Properties	Active Brine Well	Active Brine Well
Loving	Blk 01-82	4230130680	Chapman Ford #BR1	Herricks & Son Co.	Plugged Brine Well	Plugged Brine Well
Loving	Blk 33-80	4230180318	Mentone Brine Station #1D	Basic Energy Services	Active Brine Well	Active Brine Well
Loving	Blk 29-28	4230180319	East Mentone Brine Station #1	Permian Brine Sales, Inc.	Plugged Brine Well	Plugged Brine Well
Loving	Blk 01-83	4230180320	North Mentone #1	Chance Properties	Active Brine Well	Active Brine Well
Reeves	Blk 56-30	4238900408	Orla Brine Station #1D	Mesquite SWD Inc.	Active Brine Well	Active Brine Well
Reeves	Blk 04-08	4238920100	North Pecos Brine Station #WD-1	Chance Properties	Active Brine Well	Active Brine Well
Reeves	Blk 07-21	4238980476	Coyanosa Brine Station #1	Chance Properties	Active Brine Well	Active Brine Well
Ward	Blk 17-20	4247531742	Pyote Brine Station #WD-1	Chance Properties	Active Brine Well	Active Brine Well
Ward	Blk 01-13	4247534514	Quito West Unit #207	Seaboard Oil Co.	Active Brine Well	Active Brine Well
Ward	Blk 34-200	4247520329	Barstow Brine Station #1	Basic Energy Services, LP	--	**Active Brine Well**
Ward	Blk 34-174	4247582265	Barstow Brine Station #1	Energy Equity Company	Active Brine Well	Active Brine Well

† **Bold type** indicates a change from CRA-2009.

In single-borehole operations, a borehole is drilled into the upper part of the halite unit. After casing and cementing this portion of the borehole, the borehole is extended, uncased, into the halite formation. An inner pipe is installed from the surface to the base of this uncased portion of the borehole. During operation, fresh water is pumped down the annulus of the borehole.

This dissolves halite over the uncased portion of the borehole, and saturated brine is forced up the inner tube to the surface.

In doublet operations, a pair of boreholes are drilled, cased, and cemented into the upper part of the halite unit. The base of the production well is set some feet below the base of the injection well. In the absence of natural fractures or other connections between the boreholes, hydrofracturing is used to induce fractures around the injection well. During operation, fresh water is pumped down the injection well. This initially dissolves halite from the walls of the fractures and the resulting brine is then pumped from the production well. After a period of operation a cavity develops between the boreholes as the halite between fractures is removed. Because of its lower density, fresh water injected into this cavity will rise to the top and dissolve halite from the roof of the cavity. As the brine density increases it sinks within the cavern and saturated brine is extracted from the production well.

SCR-5.2.2.4.4.1 Current Brine Wells within the Delaware Basin

Brine wells are classified as Class II injection wells. In the Delaware Basin, the process includes injecting fresh water into a salt formation to create a saturated brine solution which is then extracted and utilized as a drilling agent. These wells are tracked by the DBDSP on a continuing basis. Supplemental information provided to the EPA in 1997 showed 11 brine wells in the Delaware Basin. Since that time, additional information has shown that there are 16 brine wells within the Delaware basin, of which 4 are plugged and abandoned. This results in 12 currently active brine wells. Table SCR-2 provides information on these wells. While these wells are within the Delaware Basin, none are within the vicinity of the WIPP. The nearest operating brine well is the Dunaway #1, which is approximately 22 mi (35.4 km) from the WIPP.

Two New Mexico operating brine wells collapsed in 2008, causing surface sinkholes. A subsurface cavern associated with a brine well 17.3 mi (27.8 km) southeast of Artesia, New Mexico collapsed on July 16, 2008. Later, on November 3, 2008 a brine well collapsed near Loco Hills, New Mexico. Both of these wells are located outside the Delaware Basin. These collapses prompted the New Mexico Energy, Minerals, and Natural Resources Secretary to issue a six-month moratorium on new brine wells, and also prompted a reevaluation of New Mexico Oil Conservation Division (NMOCD) rules and policies regarding brine wells. The state reviewed all active brine wells and determined that the Eugenie #WS-1, located within the city limits of Carlsbad, (approximately 30 mi (48 km) from the WIPP) was at risk of collapse. Due to these concerns, the Eugenie #1 was plugged and removed from service in late 2008. The NMOCD has since contracted a private engineering firm to install monitoring equipment at the Eugenie #1 site to warn of imminent collapse. The NMOCD continues to gather information regarding this and all brine wells in the state to assess the future risk of collapses from existing wells and the potential impacts. The division is also considering redefining the allowable criteria for the proper siting, construction, operation, and closure of brine operations.

SCR-5.2.2.4.5 Solution Mining for Other Minerals

Currently, there are no ongoing solution mining activities within the vicinity of the WIPP. The Rustler Springs sulfur mine located in Culberson County, Texas, began operations in 1969 and continued until it was officially closed in 1999. This mine used the Frasch process (superheated water injection) to extract molten sulfur (Cunningham 1999).

SCR-5.2.2.4.6 Solution Mining for Gas Storage

No gas storage cavities have been solution mined within the New Mexico portion of the Delaware Basin. Five gas storage facilities exist within the general vicinity of the WIPP; however, only one is within the Delaware basin. This one New Mexico Delaware Basin facility uses a depleted gas reservoir for storage and containment; it was not solution mined (see Appendix DATA-2004, Attachment A, Section DATA-A-5.4).

SCR-5.2.2.4.7 Solution Mining for Disposal

Solution mining can be used to create a disposal cavity in bedded salt. Such disposal cavities can be used for the disposal of naturally occurring radioactive material or other wastes. No such cavities have been mined or operated within the vicinity of the WIPP.

SCR-5.2.2.4.8 Effects of Solution Mining

SCR-5.2.2.4.8.1 Subsidence

Regardless of whether the single-borehole or two-borehole technique is used for solution mining, the result is a subsurface cavity which could collapse and lead to subsidence of overlying strata. In a response to the Environmental Evaluation Group comment, the DOE effectively argued that, "If solution mining for potash were undertaken in the vicinity of the WIPP it could result in subsidence. However, performance assessment calculations already assume that widespread subsidence will occur as a result of potash mining in the near future. The assumed extent of subsidence and its effects on the hydraulic conductivity of Culebra are independent of the mining methods used (underground excavation or solution mining)." (U.S. EPA 1998d). While this FEP is primarily concerned with solution mining for other minerals (not potash), this argument holds for the removal of any mineral via the solution process (i.e., brine production).

SCR-5.2.2.4.8.2 Hydrogeological Effects

In regions where solution mining takes place, the hydrogeology could be affected in a number ways:

- Subsidence above a large dissolution cavity could change the vertical and lateral hydraulic conductivity of overlying units.

- Extraction of fresh water from aquifers for solution mining could cause local changes in pressure gradients.

- Loss of injected fresh water or extracted brine to overlying units could cause local changes in pressure gradients.

The potential for subsidence to take place above solution mining operations in the region of Carlsbad, New Mexico is discussed above. Some subsidence could occur in the future if brine operations continue at existing wells. Resulting fracturing may change permeabilities locally in overlying formations. However, because of the restricted scale of the solution mining at a particular site, and the distances between such wells, such fracturing will have no significant effect on hydrogeology near the WIPP.

Solution mining operations in the Delaware Basin extract water from shallow aquifers so that, even if large drawdowns are permitted, the effects on the hydrogeology will be limited to a relatively small area around the operation. Since all the active operations are more than 32 km (20 mi) from the WIPP, there will be no significant effects on the hydrogeology near the WIPP.

Discharge plans for solution mining operations typically include provision for annual mechanical integrity tests at one and one-half the normal operating pressure for four hours (New Mexico Oil Conservation Division 1994). Thus, the potential for loss of integrity and consequent leakage of freshwater or brine to overlying formations is low. If, despite these annual tests, large water losses did take place from either injection or production wells, the result would be low brine yields and remedial actions would most likely be taken by the operators.

SCR-5.2.2.4.8.3 Geochemical Effects

Solution mining operations could affect the geochemistry of surface or subsurface water near the operation if there were brine leakage from storage tanks or production wells. Discharge plans for solution mining operations specify the measures to be taken to prevent leakage and to mitigate the effects of any that do take place. These measures include berms around tanks and annual mechanical integrity testing of wells (New Mexico Oil Conservation Division 1994). The potential for changes in geochemistry is therefore low, and any brine losses that did take place would be limited by remedial actions taken by the operator. In the event of leakage from a production well, the effect on geochemistry of overlying formation waters would be localized and, given the distance of such wells from the WIPP site, such leakage would have no significant effect on geochemistry near the WIPP.

SCR-5.2.2.4.9 Conclusion of Low Consequence

Brine production through solution mining takes place in the Delaware Basin, and the DOE assumes it will continue in the near future. Because of the existence of these solution operations, it is not possible to screen this activity based on the provisions of section 194.25(a). However, despite oil and gas exploration and production taking place in the vicinity of the WIPP site, the nearest operating solution mine is more than 32 km (20 mi) from the WIPP site. These locations are too far from the WIPP site for any changes in hydrogeology or geochemistry, from subsidence or fresh water or brine leakage, to affect the performance of the disposal system. Thus, the effects of HCN and future solution mining for other resources in the Delaware Basin can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.3 Explosion-Induced Flow

SCR-5.2.3.1 **FEP Number:** H39
FEPs Title: *Changes in Groundwater Flow Due to Explosions*

SCR-5.2.3.1.1 Screening Decision: SO-C (HCN)
SO-R (Future)

Changes in Groundwater Flow due to Explosions (HCN) have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Changes in groundwater flow that may be caused by future explosions have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.3.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.2.3.1.3 Screening Argument

SCR-5.2.3.1.3.1 Historical, Current, and Near-Future Human EPs

The small-scale explosions that have been used in the Delaware Basin to fracture oil- and natural-gas-bearing units to enhance resource recovery have been too deep to have disturbed the hydrology of the disposal system (see FEP H19, Section SCR-5.1.3.1).

Also, as discussed in Section SCR-5.1.3.2 (*Underground Nuclear Device Testing* [H20]), the Delaware Basin has been used for an isolated nuclear test (Project Gnome), approximately 13 km (8 mi) southwest of the WIPP waste disposal region. An induced zone of increased permeability was observed to extend 46 m (150 ft) laterally from the point of the explosion. The increase in permeability was primarily associated with motions and separations along bedding planes, the major preexisting weaknesses in the rock. This region of increased permeability is too far from the WIPP site to have had a significant effect on the hydrological characteristics of the disposal system. Thus, changes in groundwater flow due to explosions in the past have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.3.1.3.2 Future Human EPs

The criterion in section 194.32(a) relating to the scope of PAs limits the consideration of future human actions to mining and drilling. Also, consistent with section 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, changes in groundwater flow due to explosions in the future have been eliminated from PA calculations on regulatory grounds.

SCR-5.3 Geomorphological EPs

SCR-5.3.1 Land Use Changes

SCR-5.3.1.1 FEP Number: H40
FEP Title: *Land Use Changes*

SCR-5.3.1.1.1 Screening Decision: SO-R (HCN)
SO-R (Future)

Land Use Changes have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.3.1.1.3 Screening Argument

This section discusses surface activities that could affect the geomorphological characteristics of the disposal system and result in changes in infiltration and recharge conditions. The potential effects of water use and control on disposal system performance are discussed in FEPs H42 through H46 (Section SCR-5.4.1.1, Section SCR-5.4.1.2, and Section SCR-5.4.1.3).

SCR-5.3.1.1.4 Historical, Current, and Near-Future Human EPs

Surface activities that take place at present in the vicinity of the WIPP site include those associated with potash mining, oil and gas reservoir development, water extraction, and grazing. Additionally, a number of archeological investigations have taken place within the controlled area that were aimed at protecting and preserving cultural resources. Elsewhere in the Delaware Basin, sand, gravel, and caliche are produced through surface quarrying. The only surface activity that has the potential to affect the disposal system is potash tailings, salt tailings (both potash and WIPP), and effluent disposal. Potash tailings ponds may act as sources of focused recharge to the Dewey Lake and Rustler units.

Three potash tailings piles/ponds are in operation that might be influencing groundwater flow at the WIPP site. These are the Mississippi Potash Inc. (MPI) East tailings pile, approximately 10 km (6 mi) due north of the WIPP, the MPI West tailings pile in the northwest arm of Nash Draw, and the IMC Kalium tailings pile, approximately 10 km (6 mi) due west of the WIPP in Nash Draw. These tailings piles have been in operation for decades—disposal at the MPI East site, the youngest of the piles, began in 1965. Brine disposal at these locations affects Rustler groundwaters in Nash Draw, as shown by the hydrochemical facies D waters described by Siegel et al. (1991, p. 2-61). Brine disposal also affects heads in Nash Draw, and these head effects likely propagate to the WIPP site as well. These effects, however, predate water-level monitoring for the WIPP and have been implicitly included when defining boundary heads for Culebra flow models. The Culebra T-fields developed for the CRA-2009 PABC (also used in this CRA-2014) include data gathered since 2000 to define model boundary conditions. Thus, the effects of brine disposal at the tailings piles can be considered to be included in PA calculations. These effects are expected to continue in the near future.

The Delaware Basin monitoring program monitors land use activities in the WIPP vicinity. This program has not identified new planned uses for land in the vicinity of the WIPP (U.S. DOE 2012). Therefore, consistent with the criteria in section 194.32(c) and section 194.54(b) (U.S. EPA 1996a), land use changes in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.1.5 Future Human EPs

The criterion in section 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." Therefore, no future land use change*s* need be considered in the vicinity of the WIPP, and they have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.2 **FEP Number:** H41
FEP Title: *Surface Disruptions*

SCR-5.3.1.2.1 Screening Decision: UP (HCN)
SO-C (Future)

The effects of HCN *Surface Disruptions* are accounted for in PA calculations. The effects of future *Surface Disruptions* have been eliminated from PA calculations on the basis of low consequence.

SCR-5.3.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.3.1.2.3 Screening Argument

This section discusses surface activities that could affect the geomorphological characteristics of the disposal system and result in changes in infiltration and recharge conditions. The potential effects of water use and control on disposal system performance are discussed in FEPs H42 through H46.

SCR-5.3.1.2.4 Historical, Current, and Near-Future Human EPs

Most surface activities have no potential to affect the disposal system and are, therefore, screened out on the basis of low consequence (e.g., archaeological excavations and arable farming). However, the effects of activities capable of altering the disposal system (disposal of potash effluent) are included in the modeling of current conditions (i.e., heads) at and around the site. Discussion regarding these anthropogenic effects is found in the CRA-2004, Chapter 2.0, Section 2.2.1.4.2.2.

Surface activities that take place at present in the vicinity of the WIPP site include those associated with potash mining, oil and gas reservoir development, water extraction, and grazing. Additionally, a number of archeological investigations have taken place within the controlled area that were aimed at protecting and preserving cultural resources. Elsewhere in the Delaware Basin, sand, gravel, and caliche are produced through surface quarrying. The only surface activity that has the potential to affect the disposal system is potash tailings, salt tailings (both potash and WIPP), and effluent disposal. Potash tailings ponds may act as sources of focused recharge to the Dewey Lake and Rustler units.

Three potash tailings piles/ponds are in operation that might be influencing groundwater flow at the WIPP site. These are the MPI East tailings pile, approximately 10 km (6 mi) due north of the WIPP, the MPI West tailings pile in the northwest arm of Nash Draw, and the IMC Kalium tailings pile, approximately 10 km (6 mi) due west of the WIPP in Nash Draw. These tailings piles have been in operation for decades—disposal at the MPI East site, the youngest of the piles, began in 1965. Brine disposal at these locations affects Rustler groundwaters in Nash Draw, as shown by the hydrochemical facies D waters described by Siegel et al. (Siegel et al. 1991, p. 2-61). Brine disposal also affects heads in Nash Draw, and these head effects likely propagate to the WIPP site as well. These effects, however, predate water-level monitoring for the WIPP and have been implicitly included when defining boundary heads for Culebra flow models. The Culebra T-fields developed for the CRA-2009 PABC (also used in this CRA-2014) include data gathered since 2000 to define model boundary conditions. Thus, the effects of brine disposal at the tailings piles can be considered to be included in PA calculations. These effects are expected to continue in the near future.

SCR-5.3.1.2.5 Future Human EPs

Future tailings ponds, if situated in Nash Draw, are expected to change Culebra (and Magenta) heads, similar to existing ones. Future tailings ponds outside of Nash Draw would not be expected to alter Culebra heads because leakage from the ponds would not be able to propagate through the low-permeability lower Dewey Lake clastics and Rustler anhydrites overlying the Culebra during the 100 yrs or less that such a pond might be in operation. Because PA calculations already include the present-day effects of tailings ponds in Nash Draw on heads, as well as the effects of future potash mining on the permeability of the Culebra (which has much greater potential to alter flow than changes in head), future surface disruptions affecting hydrologic or geologic conditions (such as potash tailings ponds) may be screened out on the basis of low consequence.

SCR-5.4 Surface Hydrological EPs

SCR-5.4.1 Water Control and Use

SCR-5.4.1.1

FEP Numbers: H42, H43, and H44
FEP Titles: *Damming of Streams and Rivers* (H42)
Reservoirs (H43)
Irrigation (H44)

SCR-5.4.1.1.1 Screening Decision: SO-C (HCN)
SO-R (Future)

The effects of HCN *Damming of Streams and Rivers*, *Reservoirs*, and *Irrigation* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Damming of Streams and Rivers*, *Reservoirs*, and *Irrigation* have been eliminated from PA calculations on regulatory grounds.

SCR-5.4.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.4.1.1.3 Screening Argument

Irrigation and damming, as well as other forms of water control and use, could lead to localized changes in recharge, possibly leading to increased heads locally, thereby affecting flow directions and velocities in the Rustler and Dewey Lake.

SCR-5.4.1.1.4 Historical, Current, and Near-Future Human EPs

In the WIPP area, two topographically low features, the Pecos River and Nash Draw, are sufficiently large to warrant consideration for damming. Dams and reservoirs already exist along the Pecos River. However, the Pecos River is far enough from the waste panels (19 km [12 mi]) that the effects of damming of streams and rivers and reservoirs can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Nash Draw is not currently dammed, and based on current hydrological and climatic conditions, there is no reason to believe it will be dammed in the near future.

Irrigation uses water from rivers, lakes, impoundments, and wells to supplement the rainfall in an area to grow crops. Irrigation in arid environments needs to be efficient and involves the spreading of a relatively thin layer of water for uptake by plants, so little water would be expected to infiltrate beyond the root zone. However, some water added to the surface may infiltrate and reach the water table, affecting groundwater flow patterns. Irrigation currently takes place on a small scale within the Delaware Basin but not in the vicinity of the WIPP, and the extent of irrigation is not expected to change in the near future. Such irrigation has no significant effect on the characteristics of the disposal system. Thus, the effects of irrigation have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.4.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in section 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future damming of streams and rivers, reservoirs, and irrigation have been eliminated from PA calculations on regulatory grounds.

SCR-5.4.1.2 FEP Number: H45
FEP Title: *Lake Usage*

SCR-5.4.1.2.1 Screening Decision: SO-R (HCN)
SO-R (Future)

The effects of *Lake Usage* have been eliminated from PA calculations on regulatory grounds.

SCR-5.4.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.4.1.2.3 Screening Argument

Irrigation and damming, as well as other forms of water control and use, could lead to localized changes in recharge, possibly leading to increased heads locally, thereby affecting flow directions and velocities in the Rustler and Dewey Lake. Surface activities, such as those associated with potash mining, could also affect soil and surface water chemistry. Note that the potential effects of geomorphological changes through land use are discussed in Section SCR-5.3.1.1 and Section SCR-5.3.1.2.

SCR-5.4.1.2.4 Historical, Current, and Near-Future Human EPs

As discussed in the CCA, Chapter 2.0, Section 2.2.2, there are no major natural lakes or ponds within 8 km (5 mi) of the site. To the northwest, west, and southwest, Red Lake, Lindsey Lake, and Laguna Grande de la Sal are more than 8 km (5 mi) from the site, at elevations of 914 to 1,006 m (3,000 to 3,300 ft). Laguna Gatuña, Laguna Tonto, Laguna Plata, and Laguna Toston are playas more than 16 km (10 mi) north and are at elevations of 1,050 m (3,450 ft) or higher.

Waters from these lakes are of limited use. Therefore human activities associated with lakes have been screened out of PA calculations based on regulatory grounds supported by section 194.32(c) and section 194.54(b).

SCR-5.4.1.2.5 Future Human EPs

The EPA has provided criteria relating to future human activities in section 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future lake usage have been eliminated from PA calculations on regulatory grounds.

SCR-5.4.1.3 **FEP Number:** H46
FEP Title: *Altered Soil or Surface Water Chemistry by Human Activities*

SCR-5.4.1.3.1 Screening Decision: SO-C (HCN)
SO-R (Future)

The effects of HCN *Altered Soil or Surface Water Chemistry by Human Activities* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Future *Altered Soil or Surface Water Chemistry by Human Activities* have been eliminated from PA calculations on regulatory grounds.

SCR-5.4.1.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.4.1.3.3 Screening Argument

Irrigation and damming, as well as other forms of water control and use, could lead to localized changes in recharge, possibly leading to increased heads locally, thereby affecting flow directions and velocities in the Rustler and Dewey Lake. Surface activities, such as those associated with potash mining, could also affect soil and surface water chemistry.

SCR-5.4.1.3.4 Historical, Current, and Near-Future Human EPs

Potash mining effluent and runoff from oil fields have altered soil and surface water chemistry in the vicinity of the WIPP. However, the performance of the disposal system will not be sensitive to soil and surface water chemistry. Therefore, altered soil or surface water chemistry by human activities has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The effects of effluent from potash processing on groundwater flow are discussed in H37 (Section SCR-5.2.2.1).

SCR-5.4.1.3.5 Future Human EPs

The EPA has provided criteria relating to future human activities in section 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future altered soil or surface water chemistry by human activities have been eliminated from PA calculations on regulatory grounds.

SCR-5.5 Climatic EPs

SCR-5.5.1 Anthropogenic Climate Change

SCR-5.5.1.1 **FEP Numbers:** H47, H48, and H49
FEP Titles: *Greenhouse Gas Effects* (H47)
Acid Rain (H48)
Damage to the Ozone Layer (N49)

SCR-5.5.1.1.1 Screening Decision: SO-R (HCN)
SO-R (Future)

The effects of anthropogenic climate change (*Acid Rain*, *Greenhouse Gas Effects*, and *Damage to the Ozone Layer*) have been eliminated from PA calculations on regulatory grounds.

SCR-5.5.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.5.1.1.3 Anthropogenic Climate Change

The effects of the current climate and natural climatic change are accounted for in PA calculations, as discussed in the CCA, Chapter 6.0, Section 6.4.9, and Appendix PA-2014, Section PA-4.8. However, human activities may also affect the future climate and thereby influence groundwater recharge in the WIPP region. The effects of anthropogenic climate change may be on a local to regional scale (acid rain) or on a regional to global scale (greenhouse gas effects and damage to the ozone layer). Of these anthropogenic effects, only the greenhouse gas effect could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in section 194.25, compliance assessments and PAs need not consider indirect anthropogenic effects on disposal system performance. Therefore, the effects of anthropogenic climate change have been eliminated from PA calculations on regulatory grounds.

SCR-5.6 Marine EPs

SCR-5.6.1 Marine Activities

SCR-5.6.1.1

FEP Numbers: H50, H51, and H52
FEP Titles: *Costal Water Use* (H50)
Seawater Use (H51)
Estuarine Water Use (H52)

SCR-5.6.1.1.1 Screening Decision: SO-R (HCN)
SO-R (Future)

HCN, and future *Coastal Water Use*, *Seawater Use*, and *Estuarine Water Use* have been eliminated from PA calculations on regulatory grounds.

SCR-5.6.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.6.1.1.3 Screening Argument

This section discusses the potential for human EPs related to marine activities to affect infiltration and recharge conditions in the vicinity of the WIPP.

SCR-5.6.1.1.4 Historical, Current, and Near-Future Human EPs

The WIPP site is more than 800 km (480 mi) from the nearest seas, and hydrological conditions in the vicinity of the WIPP have not been affected by marine activities. Furthermore, consistent with the criteria in section 194.32(c) and section 194.54(b), consideration of HCN human activities is limited to those activities that have occurred or are expected to occur in the vicinity of the disposal system. Therefore, Human EPs related to marine activities (such as coastal water use, seawater use, and estuarine water use) have been eliminated from PA calculations on regulatory grounds.

SCR-5.6.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in section 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future marine activities (such as coastal water use, seawater use, and estuarine water use) have been eliminated from PA calculations on regulatory grounds.

SCR-5.7 Ecological EPs

SCR-5.7.1 Agricultural Activities

SCR-5.7.1.1

FEP Numbers: H53, H54, and H55
FEP Titles: *Arable Farming* (H53)
Ranching (H54)
Fish Farming (H55)

SCR-5.7.1.1.1 Screening Decision: SO-C (HCN) (H53, H54)

SO-R (HCN) (H55)
SO-R (Future) (H53, H54, H55)

The effects of HCN *Ranching* and *Arable Farming* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The effects of changes in future *Ranching* and *Arable Farming* practices have been eliminated from PA calculations on regulatory grounds. *Fish Farming* has been eliminated from PA calculations on regulatory grounds.

SCR-5.7.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.7.1.1.3 Screening Argument

Agricultural activities could affect infiltration and recharge conditions in the vicinity of the WIPP. Also, application of acids, oxidants, and nitrates during agricultural practice could alter groundwater geochemistry.

SCR-5.7.1.1.4 Historical, Current, and Near-Future Human EPs

Grazing leases exist for all land sections immediately surrounding the WIPP and grazing occurs within the controlled area (see the CCA, Chapter 2.0, Section 2.3.2.2). Although grazing and related crop production have had some control on the vegetation at the WIPP site, these activities are unlikely to have affected subsurface hydrological or geochemical conditions. The climate, soil quality, and lack of suitable water sources all mitigate against agricultural development of the region in the near future. Therefore, the effects of HCN ranching and arable farming have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Consistent with the criteria in section 194.32(c) and section 194.54(b), agricultural activities, such as fish farming, that have not taken place and are not expected to take place in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in section 194.32(a) that limit the scope of consideration of future human activities in PAs to mining and drilling. Also, the criterion in section 194.25(a) concerned with predictions of the future states of society requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, the effects of changes in future agricultural practices (such as ranching, arable farming, and fish farming) have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.2 Social and Technological Development

SCR-5.7.2.1 **FEP Number:** H56

FEP Title: *Demographic Change and Urban Development*

SCR-5.7.2.1.1 Screening Decision: SO-R (HCN)

SO-R (Future)

Demographic Change and Urban Development in the near future and in the future have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.2.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.7.2.1.3 Screening Argument

Social and technological changes in the future could result in the development of new communities and new activities in the vicinity of the WIPP that could have an impact on the performance of the disposal system.

Demography in the WIPP vicinity is discussed in the CCA, Chapter 2.0, Section 2.3.2.1. The community nearest to the WIPP site is the town of Loving, 29 km (18 mi) west-southwest of the site center. There are no existing plans for urban developments in the vicinity of the WIPP in the near future. Furthermore, the criterion in section 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, demographic change and urban development in the vicinity of the WIPP and technological developments have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.2.2 FEP Number: H57
FEP Title: *Loss of Records*

SCR-5.7.2.2.1 Screening Decision: Not Applicable (N/A) (HCN)
DP (Future)

Loss of Records in the future is accounted for in PA calculations.

SCR-5.7.2.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-5.7.2.2.3 Screening Argument

Because the DOE will maintain control for the current period throughout the active institutional period (100 yrs after closure), inadvertent drilling intrusion resulting from the loss of records is not applicable during the HCN period. However, PAs must consider the potential effects of human activities that might take place within the controlled area at a time when institutional controls cannot be assumed to eliminate completely the possibility of human intrusion. Consistent with section 194.41(b) (U.S. EPA 1996a), the DOE assumes no credit for AICs for more than 100 yrs after disposal. Also, consistent with section 194.43(c) (U.S. EPA 1996a), the DOE originally assumed in the CCA that passive institutional controls (PICs) do not eliminate the likelihood of future human intrusion entirely. The provisions at section 194.43(c) allow credit for PICs by reducing the likelihood of human intrusions for several hundred yrs. In U.S. DOE 1996a, the DOE took credit for these controls that include records retention by reducing the probability of intrusion for the first 600 yrs after active controls cease. The EPA disallowed this credit during the original certification (U.S. EPA 1998a). The DOE no longer takes credit for PICs in PA, effectively assuming that all public records and archives relating to the repository are lost 100 yrs after closure. Therefore, the DOE continues to include the loss of records FEP within PA and does not include credit for PICs.

SCR-6.0 Waste and Repository-Induced FEPs

This section presents screening arguments and decisions for waste- and repository-induced FEPs. There are 114 waste- and repository-induced FEPs used in the CRA-2014. Of these, 64 remain unchanged since the CRA-2009 and 50 were updated with new information.

SCR-6.1 Waste and Repository Characteristics

SCR-6.1.1 Repository Characteristics

SCR-6.1.1.1 FEP Number: W1

FEP Title: *Disposal Geometry*

SCR-6.1.1.1.1 Screening Decision: UP

The WIPP repository *Disposal Geometry* is accounted for in PA calculations.

SCR-6.1.1.1.2 Summary of New Information

The CRA-2014 will include repository changes that alter the disposal geometry. Additional tunnels in the northern region of the repository have been mined to accommodate experiments planned in the future. These experiments are not expected to affect FEPs current screening decisions, or expected repository performance. This additional mined volume (60,335 m^3) will be represented within the appropriate PA codes and models as described in Camphouse (Camphouse 2013a). This change does not affect the screening argument or decision. This FEP remains classified UP.

SCR-6.1.1.2 Screening Argument

Disposal geometry is described in the CRA-2004, Chapter 3.0, Section 3.2 and is accounted for in the setup of PA calculations (the CRA-2004, Chapter 6.0, Section 6.4.2).

SCR-6.1.2 Waste Characteristics

SCR-6.1.2.1 FEP Number: W2 and W3

FEP Title: *Waste Inventory*
Heterogeneity of Waste Forms

SCR-6.1.2.1.1 Screening Decision: UP (W2)
DP (W3)

The *Waste Inventory* and *Heterogeneity of Waste Forms* are accounted for in PA calculations.

SCR-6.1.2.1.2 Summary of New Information

The waste inventory used for the CRA-2014 PA calculations has been updated as provided in Kicker and Zeitler (Kicker and Zeitler 2013). Since these FEPs are accounted for in PA, inventory-related parameters may differ from those used in previous PAs; however, the screening decisions have not changed and these FEPs are represented in PA calculations.

SCR-6.1.2.1.3 Screening Argument

Waste characteristics, comprising the waste inventory and heterogeneity of waste forms, are described in the CCA, Appendix BIR. The waste inventory is accounted for in PA calculations in deriving the dissolved actinide source term and gas generation rates. The distribution of contact-handled transuranic (CH-TRU) and remote-handled transuranic (RH-TRU) waste within the repository leads to room-scale heterogeneity of the waste forms, which is accounted for in PA calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion (Appendix PA-2014, Section PA-3.8).

SCR-6.1.3 Container Characteristics

SCR-6.1.3.1 FEP Number: W4

FEP Title: *Container Form*

SCR-6.1.3.1.1 Screening Decision: SO-C – Beneficial

The *Container Form* has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.3.1.2 Summary of New Information

The physical form of the containers is conservatively ignored in performance calculations. However, certain aspects of the container (material composition) are accounted for in PA. The waste inventory for the CRA-2014 has been updated as detailed in Van Soest (Van Soest 2012) and contains masses of container materials. While the physical form of containers will be conservatively ignored for waste containment properties (SO-C Beneficial), other aspects of the containers will be included and updated per this new waste inventory. As such, changes represented in the inventory used for this application do not affect this FEP or its screening decision.

SCR-6.1.3.1.3 Screening Argument

The container form has been eliminated from PA calculations on the basis of its beneficial effect on retarding radionuclide release. The PA assumes instantaneous container failure and waste dissolution consistent with the source-term model, even though WIPP performance calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 yrs (see Helton et al. 1998). All these undegraded container materials will (1) prevent contact between brine and radionuclides; (2) decrease the rate and extent of radionuclide transport because of high tortuosity along the flow pathways and, as a result, increase opportunities for metallic iron (Fe) and corrosion products to beneficially reduce radionuclides to lower oxidation states. Therefore, the container form can be eliminated on the basis of its beneficial effect on retarding radionuclide transport. In the CCA, Appendix WCL, a minimum quantity of metallic Fe was specified to ensure sufficient reactants to reduce radionuclides to lower and less soluble oxidation states. This requirement is met as long as there are no substantial changes in container materials. The inventory used for the CRA-2014 contains 3.69 x 10^7 kg of steel in packaging (includes containers) materials. This value is up slightly from 3.59 x 10^7 kg reported in 2008 (Van Soest 2012). Therefore, the current inventory estimate indicates that there is a sufficient quantity of metallic iron to ensure reduction of radionuclides to lower and less soluble oxidation states.

SCR-6.1.3.2 **FEP Number:** W5
FEP Title: *Container Material Inventory*

SCR-6.1.3.2.1 Screening Decision: UP

The *Container Material Inventory* is accounted for in PA calculations.

SCR-6.1.3.2.2 Summary of New Information

The masses of container materials associated with the waste inventory for the CRA-2014 have been updated as detailed in Van Soest (Van Soest 2012).

SCR-6.1.3.2.3 Screening Argument

The container material inventory is described in Van Soest (Van Soest 2012) and is accounted for in PA calculations through the estimation of gas generation rates (see Appendix PA-2014, Section PA-4.2.5). In the CCA, Appendix WCL, a minimum quantity of metallic Fe was specified to ensure sufficient reactants to reduce radionuclides to lower and less soluble oxidation states. This requirement is met as long as there are no substantial changes in container materials. The inventory used for the CRA-2014 contains 3.69 x 10^7 kg of steel in packaging (includes containers) materials. This value is up slightly from 3.59 x 10^7 kg reported in 2008 (Van Soest 2012).

SCR-6.1.4 Seal Characteristics

SCR-6.1.4.1 **FEP Numbers:** W6, W7, W109, and W110
FEP Titles: *Shaft Seal Geometry* (W6)
Shaft Seal Physical Properties (W7)
Panel Closure Geometry (W109)
Panel Closure Physical Properties (W110)

SCR-6.1.4.1.1 Screening Decision: UP

The Shaft Seal Geometry, Shaft Seal Physical Properties, Panel Closure Geometry, and Panel Closure Properties are accounted for in PA calculations.

SCR-6.1.4.1.2 Summary of New Information

The CRA-2014 PA includes a new PCS design constructed of run-of-mine (ROM) salt, rather than the previously planned "Option D" concrete PCS. The physical dimensions of the new ROM salt PCS are also different than the "Option D" PCS. These changes affect the implementation of both W109 *Panel Closure Geometry* and W110 *Panel Closure Physical Properties*. The manner in which these changes are implemented in PA is described in Camphouse (Camphouse 2013a).

SCR-6.1.4.1.3 Screening Argument

Shaft seal characteristics, including shaft seal geometry, and physical properties are described in the CCA, Chapter 3.0, Section 3.3.2. The ROMPCS geometry and physical properties are described in Camphouse et al. (Camphouse et al. 2012). These repository elements are accounted for in PA calculations through the representation of the seal system and panel closures in BRAGFLO and the permeabilities assigned to the shaft seal and panel closure materials (see Appendix PA-2014, Section PA-4.2.7 and Section PA-4.2.8).

SCR-6.1.4.2

FEP Numbers: W8, W111
FEP Titles: *Shaft Seal Chemical Composition* (W8)
Panel Closure Chemical Composition (W111)

SCR-6.1.4.2.1 Screening Decision: SO-C Beneficial

The *Shaft Seal Chemical Composition* has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.4.2.2 Summary of New Information

The CRA-2014 includes the new ROM salt PCS. While the proposed PCS design does not include the same concrete elements as the previously planned Option D, it is still considered conservative to ignore any sorptive properties potentially present in the new design.

SCR-6.1.4.2.3 Screening Argument

The effect of shaft seal chemical composition and panel closure chemical composition on actinide speciation and mobility has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.4.2.4 Repository Seals (Shaft and Panel Closures)

Certain repository materials have the potential to interact with groundwater and significantly alter the chemical speciation of any radionuclides present. In particular, extensive use of cementitious materials in the shaft seals may have the capacity to buffer groundwaters to extremely high pH (for example, Bennett et al. 1992, pp. 315 – 325). At high pH values, the speciation and adsorption behavior of many radionuclides is such that their dissolved concentrations are reduced in comparison with near-neutral waters. This effect reduces the migration of radionuclides in dissolved form.

Several publications describe strong actinide (or actinide analog) sorption by cement (Altenheinhaese et al. 1994; Wierczinski et al. 1998; Pointeau et al. 2001), or sequestration by incorporation into cement alteration phases (Gougar et al. 1996; Dickson and Glasser 2000). These provide support for the screening argument that chemical interactions between the cement seals and the brine will be of beneficial consequence to the performance of the disposal system.

For the PCS, choosing to ignore any sorptive properties potentially present in the new design does not create an inconsistency within the current model. Radionuclide concentrations in brine are modeled to remain constant throughout each vector and are not reduced through sorption by any closure component, regardless of its composition, even though impurities in the host rock (such as clays) have sorptive properties as well as corrosion products expected to be present in the repository.

The effects of cementitious materials in shaft seals on groundwater chemistry have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.5 Backfill Characteristics

SCR-6.1.5.1 **FEP Number:** W9
FEP Title: *Backfill Physical Properties*

SCR-6.1.5.1.1 Screening Decision: SO-C

Backfill Physical Properties have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.1.5.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.1.5.1.3 Screening Argument

A chemical backfill is being added to the disposal room to buffer the chemical environment. The backfill characteristics were previously described in the CCA, Appendix BACK with additional information contained in Appendix BARRIERS-2004, Section BARRIERS-2.3.4.3. The mechanical and thermal effects of backfill are discussed in W35 (Section SCR-6.3.5.4) and W72 (Section SCR-6.3.4.1) respectively, where they have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Backfill will result in an initial permeability for the disposal room lower than that of an empty cavity, so neglecting the hydrological effects of backfill is a conservative assumption with regard to brine inflow and radionuclide migration. Thus, backfill physical properties have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.1.5.2 **FEP Number:** W10
FEP Title: *Backfill Chemical Composition*

SCR-6.1.5.2.1 Screening Decision: UP

The *Backfill Chemical Composition* is accounted for in PA calculations.

SCR-6.1.5.2.2 Summary of New Information

The CRA-2014 PA contains a refinement of water balance within the repository. This refinement is implemented within the Chemical Conditions Conceptual Model, and will include the major gas- and brine-producing and consuming reactions within the existing model, one of which is MgO hydration (see Camphouse 2013a). This model enhancement does not change the screening argument or decision for this FEP, but is mentioned here for completeness.

SCR-6.1.5.2.3 Screening Argument

A chemical backfill is added to the disposal room to buffer the chemical environment. The backfill characteristics are described in Appendix MgO-2009, Section MgO-3.0. The mechanical and thermal effects of backfill are discussed in W35 (Section SCR-6.3.5.4) and W72 (Section SCR-6.3.4.1), respectively, where they have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Backfill chemical composition is accounted for in PA calculations in deriving the dissolved and colloidal actinide source terms (see Appendix SOTERM-2014, Section SOTERM-2.3, -3.9, -4.6, and -4.7, Appendix MgO-2009, Section MgO-5.0, and Brush and Domski 2013a) and in the production of gas within the repository.

SCR-6.1.6 Post-Closure Monitoring Characteristics

SCR-6.1.6.1 **FEPs Number:** W11
FEP Title: *Post-Closure Monitoring*

SCR-6.1.6.1.1 Screening Decision: SO-C

The potential effects of *Post-Closure Monitoring* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.1.6.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.1.6.1.3 Screening Argument

Post-closure monitoring is required by section 191.14(b) (U.S. EPA 1993) as an assurance requirement to “detect substantial and detrimental deviations from expected performance.” The DOE has designed the monitoring program (see the CCA, Appendix MON) so that the monitoring methods employed are not detrimental to the performance of the disposal system (section 194.42(d)) (U.S. EPA 1996a). Nonintrusive monitoring techniques are used so that post-closure monitoring would not impact containment or require remedial activities. In summary, the effects of monitoring have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.2 Radiological FEPs

SCR-6.2.1 Radioactive Decay and Heat

SCR-6.2.1.1 **FEP Number:** W12

FEP Title: *Radionuclide Decay and Ingrowth*

SCR-6.2.1.1.1 Screening Decision: UP

Radionuclide decay and ingrowth are accounted for in PA calculations.

SCR-6.2.1.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.2.1.1.3 Screening Argument

Radionuclide decay and ingrowth are accounted for in PA calculations (see Appendix PA-2014, Section PA-4.3).

SCR-6.2.1.2 **FEP Number:** W13

FEP Title: *Heat From Radioactive Decay*

SCR-6.2.1.2.1 Screening Decision: SO-C

The effects of temperature increases as a result of *Heat From Radioactive Decay* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.2.1.2.2 Summary of New Information

The radionuclide inventory used for the CRA-2014 PA calculations (Kicker and Zeitler 2013) is lower than previously estimated for the CCA. Thus, all CRA-2014 radioactive decay heat screening arguments are bounded by the previous CCA screening arguments.

SCR-6.2.1.2.3 Screening Argument

Radioactive decay of the waste emplaced in the repository will generate heat. The importance of heat from radioactive decay depends on the effects that the induced temperature changes would have on mechanics (W29 - W31, Section SCR-6.3.4.1), fluid flow (W40 and W41, Section SCR-

6.4.1.1), and geochemical processes (W44 through W75, Section SCR-6.5.1.1, Section SCR-6.5.1.2, Section SCR-6.5.1.3, Section SCR-6.5.1.4, Section SCR-6.5.1.5, Section SCR-6.5.1.6, Section SCR-6.5.1.7, Section SCR-6.5.1.8, Section SCR-6.5.1.9, Section SCR-6.5.2.1, Section SCR-6.5.2.2, Section SCR-6.5.3.1, Section SCR-6.5.4.1, Section SCR-6.5.5.1, Section SCR-6.5.5.2, Section SCR-6.5.5.3, Section SCR-6.5.6.1, Section SCR-6.5.7.1, Section SCR-6.5.7.1, and Section SCR-6.5.7.2). For example, extreme temperature increases could result in thermally induced fracturing, regional uplift, or thermally driven flow of gas and brine in the vicinity of the repository.

The design basis for the WIPP requires that the thermal loading does not exceed 10 kilowatts (kW) per acre. Transportation restrictions also require that the thermal power generated by waste in an RH-TRU container shall not exceed 300 watts (U.S. Nuclear Regulatory Commission 2002).

The DOE has conducted numerous studies related to heat from radioactive decay. The following presents a brief summary of these past analyses. First, a numerical study to calculate induced temperature distributions and regional uplift is reported in DOE (U.S. DOE 1980, pp. 9-149 through 9-150). This study involved estimation of the thermal power of CH-TRU waste containers. The DOE (U.S. DOE 1980, p. 9-149) analysis assumed the following:

- All CH-TRU waste drums and boxes contain the maximum permissible quantity of Pu. The fissionable radionuclide content for CH-TRU waste containers was assumed to be no greater than 200 grams (g) per 0.21 m^3 (7 ounces [oz] per 7.4 ft^3) drum and 350 g/1.8 m^3 (12.3 oz/63.6 ft^3) standard waste box (^{239}Pu fissile gram equivalents).

- The Pu in CH-TRU waste containers is weapons grade material producing heat at 0.0024 watts per gram (W/g). Thus, the thermal power of a drum is approximately 0.5 W, and that of a box is approximately 0.8 W.

- Approximately 3.7×10^5 m^3 (1.3×10^7 ft^3) of CH-TRU waste are distributed within a repository enclosing an area of 7.3×10^5 m^2 (7.9×10^6 ft^2). This is a conservative assumption in terms of quantity and density of waste within the repository, because the maximum capacity of the WIPP is 1.756×10^5 m^3 (6.2×10^6 ft^3) for all waste (as specified by the LWA) to be placed in an enclosed area of approximately 5.1×10^5 m^2 (16 mi^2).

- Half of the CH-TRU waste volume is placed in drums and half in boxes so that the repository will contain approximately 900,000 drums and 900,000 boxes. Thus, a calculated thermal power of 0.7 W/m^2 (2.8 kW/acre) of heat is generated by the CH-TRU waste.

- Insufficient RH-TRU waste would be emplaced in the repository to influence the total thermal load.

Under these assumptions, Thorne and Rudeen (Thorne and Rudeen 1981) estimated the long-term temperature response of the disposal system to waste emplacement. Calculations assumed a uniform initial power density of 2.8 kW/acre (0.7 W/m^2) which decreases over time. Thorne and

Rudeen (Thorne and Rudeen 1981) attributed this thermal load to RH-TRU waste, but the DOE (U.S. DOE 1980) more appropriately attributed this thermal load to CH-TRU waste based on the assumptions listed above. Thorne and Rudeen (Thorne and Rudeen 1981) estimated the maximum rise in temperature at the center of a repository to be 1.6 °C (2.9 °F) at 80 yrs after waste emplacement.

More recently, Sanchez and Trellue (Sanchez and Trellue 1996) estimated the maximum thermal power of an RH-TRU waste container. The Sanchez and Trellue (Sanchez and Trellue 1996) analysis involved inverse shielding calculations to evaluate the thermal power of an RH-TRU container corresponding to the maximum permissible surface dose of 1,000 rem per hour (rem/hr). The following calculational steps were taken in the Sanchez and Trellue (Sanchez and Trellue 1996) analysis:

- Calculate the absorbed dose rate for gamma radiation corresponding to the maximum surface dose equivalent rate of 1,000 rem/hr. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because the maximum dose rate from neutrons is 270 millirems/hr, and the corresponding neutron heating rate will be insignificant.

- Calculate the exposure rate for gamma radiation corresponding to the absorbed dose rate for gamma radiation.

- Calculate the gamma flux density at the surface of a RH-TRU container corresponding to the exposure rate for gamma radiation. Assuming the gamma energy is 1.0 megaelectron volts, the maximum allowable gamma flux density at the surface of a RH-TRU container is about 5.8×10^8 gamma rays/cm^2/seconds (s).

- Determine the distributed gamma source strength, or gamma activity, in an RH-TRU container from the surface gamma flux density. The source is assumed to be shielded such that the gamma flux is attenuated by the container and by absorbing material in the container. The level of shielding depends on the matrix density. Scattering of the gamma flux, with loss of energy, is also accounted for in this calculation through inclusion of a gamma buildup factor. The distributed gamma source strength is determined assuming a uniform source in a right cylindrical container. The maximum total gamma source (gamma curies [Ci]) is then calculated for a RH-TRU container containing 0.89 m^3 (31.4 ft^3) of waste. For the waste of greatest expected density (about 6,000 kg/m^3 (360 lb/ft^3), the gamma source is about 2×10^4 Ci/m^3 (566 Ci/ft^3).

- Calculate the total Ci load of a RH-TRU container (including alpha and beta radiation) from the gamma load. The ratio of the total Ci load to the gamma Ci load was estimated through examination of the radionuclide inventory presented in the CCA, Appendix BIR. The gamma Ci load and the total Ci load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of total Ci load to gamma Ci load of RH-TRU waste was calculated to be 1.01.

- Calculate the thermal load of a RH-TRU container from the total Ci load. The ratio of thermal load to Ci load was estimated through examination of the radionuclide inventory presented in the CCA, Appendix BIR. The thermal load and the total Ci load for each radionuclide listed in the WIPP inventory were summed. Based on these summed loads the ratio of thermal load to Ci load of RH-TRU waste was calculated to be about 0.0037 watts per curie (W/Ci). For a gamma source of 2×10^4 Ci/m^3 (566 Ci/ft^3), the maximum permissible thermal load of a RH-TRU container is about 70 W/m^3 (2 W/ft^3). Thus, the maximum thermal load of a RH-TRU container is about 60 W, and the transportation limit of 300 W will not be achieved.

Note that Sanchez and Trellue (Sanchez and Trellue 1996) calculated the average thermal load for a RH-TRU container to be less than 1 W. Also, the total RH-TRU heat load is less than 10% of the total heat load in the WIPP. Thus, the total thermal load of the RH-TRU waste will not significantly affect the average rise in temperature in the repository resulting from decay of CH-TRU waste.

Temperature increases will be greater at locations where the thermal power of an RH-TRU container is 60 W, if any such containers are emplaced. Sanchez and Trellue (Sanchez and Trellue 1996) estimated the temperature increase at the surface of a 60 W RH-TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 W/m^3 (2 W/ft^3). These conditions represent conservative assumptions because the thermal load will decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3 °C (5.4 °F).

In summary, previous analyses have shown that the average temperature increase in the WIPP repository caused by radioactive decay of the emplaced CH- and RH-TRU waste will be less than 2 °C (3.6 °F). Temperature increases of about 3 °C (5.4 °F) may occur in the vicinity of RH-TRU containers with the highest allowable thermal load of about 60 W (based on the maximum allowable surface dose equivalent for RH-TRU containers). Potential heat generation from nuclear criticality is discussed in Section SCR-6.2.1.3 and exothermic reactions and the effects of repository temperature changes on mechanics are discussed in the set of FEPs grouped as W29, W30, W31, W72, and W73 (Section SCR-6.3.4.1). These FEPs have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Additionally, WIPP transportation restrictions and WIPP design basis loading configurations do not allow the thermal load of the WIPP to exceed 10 kW/acre (NRC 2002). Transportation requirements restrict the thermal load from RH-TRU waste containers to no more than 300 W per container (NRC 2002). However, the limit on the surface dose equivalent rate of the RH-TRU containers (1,000 rem/hr) is more restrictive and equates to a thermal load of only about 60 W per container. Based on the thermal loads permitted, the maximum temperature rise in the repository from radioactive decay heat should be less than 2 °C (3.6 °F).

The previous FEPs screening arguments for the CCA used a bounding radioactivity heat load of 0.5 W/drum for the CH-TRU waste containers. With a total CH-TRU volume of 168,500 m^3 (~5,950,000 ft^3) this corresponds to approximately 810,000 55-gal drum equivalents with a corresponding heat load of > 400 kW used for the CCA FEPs screening arguments. From Sanchez and Trellue (Sanchez and Trellue 1996), it can be seen that a realistic assessment of the heat load, based on radionuclide inventory data in the Transuranic Waste Baseline Inventory Report is less than 100 kW. Thus, the CCA FEPs incorporate a factor of safety of at least four, and heat loads from the CRA-2014 inventory would be even less.

SCR-6.2.1.3 **FEPs Number:** W14
FEPs Title: Nuclear Criticality: Heat

SCR-6.2.1.3.1 Screening Decision: SO-P

Nuclear Criticality has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.2.1.3.2 Summary of New Information

The screening argument for this FEP has been updated to reference the inventory used in the CRA-2014. The arguments and conclusions have not been changed as a result of this new information.

SCR-6.2.1.3.3 Screening Argument

Nuclear criticality refers to a sustained fission reaction that may occur if fissile radionuclides reach both a sufficiently high concentration and total mass (where the latter parameter includes the influence of enrichment of the fissile radionuclides). In the subsurface, the primary effect of a nuclear reaction is the production of heat.

Nuclear criticality (near and far field) was eliminated from PA calculations for the WIPP for waste contaminated with TRU radionuclides. The probability for criticality within the repository is low (there are no mechanisms for concentrating fissile radionuclides dispersed amongst the waste). Possible mechanisms for concentration in the waste disposal region include high solubility, compaction, sorption, and precipitation. First, the maximum solubility of ^{239}Pu in the WIPP repository, the most abundant fissile radionuclide, is orders of magnitude lower than necessary to create a critical solution. The same is true for ^{235}U, the other primary fissile radionuclide. Second, the waste is assumed to be compacted by repository processes to one fourth its original volume. This compaction is still an order of magnitude too disperse (many orders of magnitude too disperse if neutron absorbers that prevent criticality (for example, ^{238}U) are included). Third, any potential sorbents in the waste would be fairly uniformly distributed throughout the waste disposal region; consequently, concentration of fissile radionuclides in localized areas through sorption is improbable. Fourth, precipitation requires significant localized changes in brine chemistry; small local variations are insufficient to separate substantial amounts of ^{239}Pu from other actinides in the waste disposal region (for example, 11 times more ^{238}U is present than ^{239}Pu).

Criticality away from the repository (following an inadvertent human intrusion) has a low probability because (1) the amount of fissile material transported from the repository is small; (2) host rock media have small porosities (insufficient for the generation of a sizable precipitation zone); and (3) no credible mechanism exists for concentrating fissile material during transport (the natural tendency is for transported material to be dispersed). As discussed in the CRA-2004, Chapter 6.0, Section 6.4.6.2, and Appendix PA-2004, Attachment MASS, Section MASS-15.0, the dolomite porosity consists of intergranular porosity, vugs, microscopic fractures, and macroscopic fractures. As discussed in the CRA-2004, Chapter 6.0, Section 6.4.5.2, porosity in the MBs consists of partially healed fractures that may dilate as pressure increases. Advective flow in both units occurs mostly through macroscopic fractures. Consequently, any potential deposition through precipitation or sorption is constrained by the depth to which precipitation and sorption occur away from fractures. This geometry is not favorable for fission reactions and eliminates the possibility of criticality. Thus, nuclear criticality has been eliminated from PA calculations on the basis of low probability of occurrence.

Additionally, screening arguments made in Rechard et al. (Rechard et al. 1996) are represented in greater detail in Rechard et al. (Rechard et al. 2000 and Rechard et al. 2001). A major finding among the analysis results in the screening arguments is the determination that fissile material would need to be reconcentrated by three orders of magnitude in order to be considered in a criticality scenario. Because inventory values reported in Kicker and Zeitler (Kicker and Zeitler 2013) are below that used in previous calculations, screening analyses for nuclear criticality are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, Rechard et al. 2000, and Rechard et al. 2001).

SCR-6.2.2 Radiological Effects on Material Properties

SCR-6.2.2.1 **FEP Numbers:** W15, W16, W17, and W112
FEP Titles: *Radiological Effects on Waste* (W15)
Radiological Effects on Containers (W16)
Radiological Effects on Shaft Seals (W17)
Radiological Effects on Panel Closures (W112)

SCR-6.2.2.1.1 Screening Decision: SO-C

Radiological Effects on the properties of the *Waste*, *Containers*, *Shaft Seals*, and *Panel Closures* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.2.2.1.2 Summary of New Information

The screening arguments for these FEPs have been updated to include references to the radionuclide inventory used for CRA-2014 PA calculations.

SCR-6.2.2.1.3 Screening Argument

Ionizing radiation can change the physical properties of many materials. Strong radiation fields could lead to damage of waste matrices, brittleness of the metal containers, and disruption of any crystalline structure in the seals. The low level of activity of the waste in the WIPP is unlikely to generate a strong radiation field. According to the inventory data presented in Van Soest (Van

Soest 2012) and Kicker and Zeitler (Kicker and Zeitler 2013), the overall activity for all TRU radionuclides has decreased from 3.44 × 10^6 Ci reported in the CCA, to 2.48 × 10^6 Ci in the CRA-2004, to 2.32 × 10^6 Ci in the CRA-2009, to 2.06 × 10^6 Ci for the CRA-2014. This decrease will not change the original screening argument. Furthermore, PA calculations assume instantaneous container failure and waste dissolution according to the source-term model (see the CCA, Chapter 6.0, Section 6.4.3.4, Section 6.4.3.5, and Section 6.4.3.6). Therefore, radiological effects on the properties of the waste, container, shaft seals, and panel closures have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3 Geological and Mechanical FEPs

SCR-6.3.1 Excavation-Induced Changes

SCR-6.3.1.1

FEP Numbers: W18 and W19
FEP Titles: *Disturbed Rock Zone* (W18)
Excavation-Induced Change in Stress (W19)

SCR-6.3.1.1.1 Screening Decision: UP

Excavation-induced host rock fracturing through formation of a *Disturbed Rock Zone* and *Changes in Stress* are accounted for in PA calculations.

SCR-6.3.1.1.2 Summary of New Information

Implementation of the new ROM salt PCS in PA requires new parameters for the DRZ above the PCS. Modifications to relevant parameters are described in Camphouse (Camphouse 2013a). These changes are downstream of the FEPs screening process, and will not change the screening decision; these FEPs will remain classified UP.

SCR-6.3.1.1.3 Screening Argument

Construction of the repository has caused local excavation-induced changes in stress in the surrounding rock as discussed in the CCA, Chapter 3.0, Section 3.3.1.5. Excavation-induced changes in stress has led to failure of intact rock around the opening, creating a DRZ of fractures. On completion of the WIPP excavation, the extent of the induced stress field perturbation will be sufficient to have caused dilation and fracturing in the anhydrite layers “a” and “b,” MB 139, and, possibly, MB 138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and MBs will alter the permeability and effective porosity of the rock around the repository, providing enhanced pathways for flow of gas and brine between the waste-filled rooms and the nearby interbeds. This excavation-induced, host-rock fracturing is accounted for in PA calculations (the CCA, Chapter 6.0, Section 6.4.5.3).

SCR-6.3.1.2 FEP Numbers: W20 and W21

FEP Titles: *Salt Creep* (W20)
Change in the Stress Field (W21)

SCR-6.3.1.2.1 Screening Decision: UP

Salt Creep in the Salado and any resultant *Changes in the Stress Field* are accounted for in PA calculations.

SCR-6.3.1.2.2 Summary of New Information

Salt creep and changes in stress will affect the consolidation of the ROM salt PCS over time. Modifications to relevant parameters are described in Camphouse (Camphouse 2013a). These changes are downstream of the FEPs screening process, and will not change the screening decision; these FEPs will remain classified UP.

SCR-6.3.1.2.3 Screening Argument

Salt creep will lead to changes in the stress field, compaction of the waste and containers, and consolidation of the long-term components of the sealing system. It will also tend to close fractures in the DRZ, leading to reductions in porosity and permeability, increases in pore fluid pressure, and reductions in fluid flow rates in the repository. Salt creep in the Salado is accounted for in PA calculations (the CCA, Chapter 6.0, Section 6.4.3.1). The long-term repository seal system relies on the consolidation of the crushed-salt seal material and healing of the DRZ around the shaft seals and in and around the panel closures to achieve a low permeability under stresses induced by salt creep. Shaft seal and panel closure performance is discussed further in Section SCR-6.3.5.1 (FEPs W36, W37, W113, and W114).

SCR-6.3.1.3 FEP Number: W22

FEP Title: *Roof Falls*

SCR-6.3.1.3.1 Screening Decision: UP

The potential effects of *Roof Ralls* on flow paths are accounted for in PA calculations.

SCR-6.3.1.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.3.1.3.3 Screening Argument

Instability of the DRZ could lead to localized roof falls in the first few hundred yrs. If instability of the DRZ causes roof falls, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep. 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, because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in PA assumes that a higher permeability zone remains for the long term. Thus, the potential effects of roof falls on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ.

SCR-6.3.1.4 **FEP Numbers:** W23 and W24

FEP Titles: *Subsidence* (W23)
Large Scale Rock Fracturing (W24)

SCR-6.3.1.4.1 Screening Decision(s): SO-C (W23)

SO-P (W24)

Fracturing within units overlying the Salado and surface displacement caused by *Subsidence* associated with repository closure have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The potential for excavation- or repository-induced *Subsidence* to create *Large Scale Rock Fracturing* and fluid flow paths between the repository and units overlying the Salado has been eliminated from PA calculations on the basis of the low probability of occurrence over 10,000 yrs.

SCR-6.3.1.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.3.1.4.3 Screening Argument

Instability of the DRZ could lead to localized roof falls in the first few hundred yrs. If instability of the DRZ causes roof falls, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep and the local lithologies. 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. Because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in PA assumed that a higher-permeability zone remained for the long term. The CCA PAVT modified the DRZ permeability to a sampled range. Thus, the potential effects of roof falls on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ.

The amount of subsidence that can occur as a result of salt creep closure or roof collapse in the WIPP excavation depends primarily on the volume of excavated rock, the initial and compressed porosities of the various emplaced materials (waste, backfill, panel and drift closures, and seals), the amount of inward creep of the repository walls, and the gas and fluid pressures within the repository. The DOE (Westinghouse 1994) has analyzed potential excavation-induced subsidence with the primary objective of determining the geomechanical advantage of backfilling the WIPP excavation. The DOE (Westinghouse 1994, pp. 3-4 through 3-23) used mass conservation calculations, the influence function method, the National Coal Board empirical method, and the two-dimensional, finite-difference-code, Fast Lagrangian Analysis of Continua (FLAC) to estimate subsidence for conditions ranging from no backfill to emplacement of a highly compacted crushed-salt backfill. The DOE (Westinghouse 1994, pp. 2-17 to 2-23) also investigated subsidence at potash mines located near the WIPP site to gain insight into the expected subsidence conditions at the WIPP and to calibrate the subsidence calculation methods.

Subsidence over potash mines will be much greater than subsidence over the WIPP because of the significant differences in stratigraphic position, depth, extraction ratio, and layout. The WIPP site is located stratigraphically lower than the lowest potash mine, which is near the base of the McNutt. At the WIPP site, the base of the McNutt is about 150 m (490 ft) above the repository horizon. The WIPP rock extraction ratio in the waste disposal region will be about 22%, as compared to 65% for the lowest extraction ratios within potash mines investigated by the DOE (Westinghouse 1994, p. 2-17).

The DOE (Westinghouse 1994, p. 2-22) reported the maximum total subsidence at potash mines to be about 1.5 m (5 ft). This level of subsidence has been observed to have caused surface fractures. However, the DOE (Westinghouse 1994, p. 2-23) found no evidence that subsidence over potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the land surface. The level of disturbance caused by subsidence above the WIPP repository will be less than that associated with potash mining and thus, by analogy, will not create fluid flow paths between the repository and the overlying units.

The various subsidence calculation methods used by the DOE (Westinghouse 1994, pp. 3-4 to 3-23) provided similar and consistent results, which support the premise that subsidence over the WIPP will be less than subsidence over potash mines. Estimates of maximum subsidence at the land surface for the cases of no backfill and highly compacted backfill are 0.62 m (2 ft) and 0.52 m (1.7 ft), respectively. The mass conservation method gave the upper bound estimate of subsidence in each case. The surface topography in the WIPP area varies by more than 3 m (10 ft), so the expected amount of repository-induced subsidence will not create a basin, and will not affect surface hydrology significantly. The DOE (Westinghouse 1994, Table 3-13) also estimated subsidence at the depth of the Culebra using the FLAC model for the case of an empty repository (containing no waste or backfill). The FLAC analysis assumed the Salado to be halite and the Culebra to have anhydrite material parameters.

Maximum subsidence at the Culebra was estimated to be 0.56 m (1.8 ft). The vertical strain was concentrated in the Salado above the repository. Vertical strain was less than 0.01% in units overlying the Salado and was close to zero in the Culebra (Westinghouse 1994, Figure 3-40). The maximum horizontal displacement in the Culebra was estimated to be 0.02 m (0.08 ft), with a maximum tensile horizontal strain of 0.007%. The DOE (Westinghouse 1994, 4-1 to 4-2) concluded that the induced strains in the Culebra will be uniformly distributed because no large-scale faults or discontinuities are present in the vicinity of the WIPP. Furthermore, strains of this magnitude would not be expected to cause extensive fracturing.

At the WIPP site, the Culebra transmissivity varies spatially over approximately five orders of magnitude (see Appendix TFIELD-2009, Figure TFIELD-64). Where transmissive horizontal fractures exist, hydraulic conductivity in the Culebra is dominated by flow through the fractures. An induced tensile vertical strain may result in an increase in fracture aperture and corresponding increases in hydraulic conductivity. The magnitude of increase in hydraulic conductivity can be estimated by approximating the hydrological behavior of the Culebra with a simple conceptual model of fluid flow through a series of parallel fractures with uniform properties. A conservative estimate of the change in hydraulic conductivity can be made by assuming that all the vertical strain is translated to fracture opening (and none to rock expansion). This method for evaluating changes in hydraulic conductivity is similar to that used by the EPA in estimating the effects of subsidence caused by potash mining (Peake 1996; U.S. EPA 1996c).

The equivalent porous medium hydraulic conductivity, K (m/s), of a system of parallel fractures can be calculated assuming the cubic law for fluid flow (Witherspoon et al. 1980):

$$K = \frac{w^3 \rho g N}{12 \mu D} \qquad \text{(SCR.10)}$$

where w is the fracture aperture, ρ is the fluid density (taken to be 1,000 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2 (32 ft) per second squared), μ is the fluid viscosity (taken as 0.001 pascal seconds), D is the effective Culebra thickness (7.7 m (26.3 ft)), and N is the number of fractures. For 10 fractures with a fracture aperture, w, of 6×10^{-5} m (2×10^{-4} ft), the Culebra hydraulic conductivity, K, is approximately 7 m per yr (2×10^{-7} m (6.5×10^{-7} ft) per second). The values of the parameters used in this calculation are within the range of those expected for the Culebra at the WIPP site (Appendix TFIELD-2009).

The amount of opening of each fracture as a result of subsidence-induced tensile vertical strain, ε, (assuming rigid rock), is $D\varepsilon/N$ meters. Thus, for a vertical strain of 0.0001, the fracture aperture, w, becomes approximately 1.4×10^{-4} m. The Culebra hydraulic conductivity, K, then increases to approximately 85 m (279 ft) per yr (2.7×10^{-6} m (8.9×10^{-6} ft) per second). Thus, on the basis of a conservative estimate of vertical strain, the hydraulic conductivity of the Culebra may increase by an order of magnitude. In PA calculations, multiple realizations of the Culebra T-fields are generated as a means of accounting for spatial variability and uncertainty . A change in hydraulic conductivity of one order of magnitude through vertical strain is within the range of uncertainty incorporated in the Culebra T-fields through these multiple realizations. Thus, changes in the horizontal component of Culebra hydraulic conductivity resulting from repository-induced subsidence have been eliminated from PA calculations on the basis of low consequence.

A similar calculation can be performed to estimate the change in vertical hydraulic conductivity in the Culebra as a result of a horizontal strain of 0.00007 m/m (Westinghouse 1994, p. 3-20). Assuming this strain to be distributed over about 1,000 fractures (neglecting rock expansion), with zero initial aperture, in a lateral extent of the Culebra of about 800 m (2,625 ft) (Westinghouse 1994, Figure 3-39), then the subsidence-induced fracture aperture is approximately 6×10^{-5} m (1.9×10^{-4} ft). Using the values for ρ, g, and μ, above, the vertical hydraulic conductivity of the Culebra can then be calculated, through an equation similar to above, to be 7 m (23 ft) per yr (2×10^{-7} m (6.5×10^{-7} ft) per second). Thus, vertical hydraulic conductivity in the Culebra may be created as a result of repository-induced subsidence, although this is expected to be insignificant.

In summary, as a result of observations of subsidence associated with potash mines in the vicinity of the WIPP, the potential for subsidence to create fluid flow paths between the repository and units overlying the Salado has been eliminated from PA calculations on the basis of low probability. The effects of repository-induced subsidence on hydraulic conductivity in the Culebra have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3.2 Effects of Fluid Pressure Changes

SCR-6.3.2.1

FEP Numbers: W25 and W26
FEP Titles: *Disruption Due to Gas Effects* (W25)
Pressurization (W26)

SCR-6.3.2.1.1 Screening Decision: UP

The mechanical effects of gas generation through *Pressurization* and *Disruption Due to Gas Effects* flow are accounted for in PA calculations.

SCR-6.3.2.1.2 Summary of New Information

Iron corrosion experiments (Wall and Enos 2006) have been completed since the CRA-2009 that provide new corrosion rates for expected WIPP-relevant conditions (Roselle 2013). These rates are implemented with a new parameter distribution type and values for the parameter STEEL:CORRMCO2. This parametric change does not affect the screening argument, decision, or the implementation of gas generation (pressurization) within PA models.

SCR-6.3.2.1.3 Screening Argument

The mechanical effects of gas generation, including the slowing creep closure of the repository because of gas pressurization and the fracturing of interbeds in the Salado through disruption due to gas effects are accounted for in PA calculations (the CCA, Chapter 6.0, Section 6.4.5.2 and Section 6.4.3.1).

SCR-6.3.3 Effects of Explosions

SCR-6.3.3.1

FEP Number: W27
FEP Title: *Gas Explosions*

SCR-6.3.3.1.1 Screening Decision: UP

The potential effects of *Gas Explosions* are accounted for in PA calculations.

SCR-6.3.3.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.3.3.1.3 Screening Argument

Explosive gas mixtures could collect in the head space above the waste in a closed panel. The most explosive gas mixture potentially generated will be a mixture of hydrogen, methane (CH_4), and oxygen, which will convert to CO_2 and water on ignition. This means that there is little likelihood of a gas explosion in the long term because the rooms and panels are expected to become anoxic and oxygen depleted. Compaction through salt creep will also greatly reduce any void space in which the gas can accumulate. Analysis (see Appendix BARRIERS-2004, Attachment PCS) indicates that the most explosive mixture of hydrogen, CH_4, and oxygen will be present in the void space approximately 20 yrs after panel-closure emplacement. This possibility of an explosion prior to the occurrence of anoxic conditions is considered in the design of the operational panel closure. The effect of such an explosion on the DRZ is expected to be no more severe than a roof fall, which is accounted for in the PA calculations (FEP W22).

SCR-6.3.3.2 **FEP Number:** W28
FEP Title: *Nuclear Explosions*

SCR-6.3.3.2.1 Screening Decision: SO-P

Nuclear Explosions have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.3.3.2.2 Summary of New Information

This FEP has been updated to include the most recent inventory information as presented in Kicker and Zeitler (Kicker and Zeitler 2013). This new information does not change the screening argument or decision for this FEP.

SCR-6.3.3.2.3 Screening Argument

Nuclear explosions have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs. For a nuclear explosion to occur, a critical mass of Pu would have to undergo rapid compression to a high density. Even if a critical mass of Pu could form in the system, there is no mechanism for rapid compression. Inventory information used for the CRA-2014 is presented in Kicker and Zeitler (Kicker and Zeitler 2013). The updated inventory information for the CRA-2014 shows a reduction of TRU radionuclides from previous estimates. Thus, current criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, Rechard et al. 2000, and Rechard et al. 2001).

SCR-6.3.4 Thermal Effects

SCR-6.3.4.1

FEP Numbers: W29, W30, W31, W72, and W73
FEP Titles: *Thermal Effects on Material Properties* (W29)
Thermally-Induced Stress Changes (W30)
Differing Thermal Expansion of Repository Components (W31)
Exothermic Reactions (W72)
Concrete Hydration (W73)

SCR-6.3.4.1.1 Screening Decision: SO-C

The effects of *Thermally-Induced Stress*, *Differing Thermal Expansion of Repository Components*, and *Thermal Effects on Material Properties* in the repository have been eliminated from PA calculations on the basis of low consequence to performance of the disposal system.

The thermal effects of *Exothermic Reactions*, including *Concrete Hydration*, have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3.4.1.2 Summary of New Information

This FEP has been updated to include the most recent inventory information as presented in Van Soest (Van Soest 2012). Thermal calculations have been updated with the updated quantities of reactants and provided below. Additionally, planned Salt Disposal Investigations (SDI) experiments as detailed in Patterson (Patterson 2011) or the Salt Defense Disposal Investigations (SDDI) (Franco 2012) will place heaters in newly excavated tunnels in the northern experimental region of the WIPP. Mining has been completed, but heater tests have not yet commenced. An evaluation conducted by Kuhlman (Kuhlman 2011) for the SDI planned change notice (PCN) shows that any thermal pulse from these experiments will be very minimal, on the order of 0.02 °C or less. Therefore, the screening argument and decision for this FEP is unaffected by the conduct of these experiments.

SCR-6.3.4.1.3 Screening Argument

Thermally induced stress could result in pathways for groundwater flow in the DRZ, in the anhydrite layers and MBs, and through seals, or it could enhance existing pathways. Conversely, elevated temperatures will accelerate the rate of salt creep and mitigate fracture development. Thermal expansion could also result in uplift of the rock and ground surface overlying the repository, and thermal buoyancy forces could lift the waste upward in the salt rock.

The distributions of thermal stress and strain changes depend on the induced temperature field and the differing thermal expansion of components of the repository, which depends on the components' elastic properties. Thermal effects on material properties (such as permeability and porosity) could potentially affect the behavior of the repository.

Exothermic reactions in the WIPP repository include MgO hydration, MgO carbonation, aluminum (Al) corrosion, and cement hydration (Bennett et al. 1996). Wang (Wang 1996) has shown that the temperature rise by an individual reaction is proportional to $\sqrt{VM}$, where V is the maximum rate of brine inflow into a waste panel for a reaction limited by brine inflow (or a specified maximum reaction rate for a reaction limited by its own kinetics) and M is the quantity of the reactant. MgO hydration, cement hydration, and Al corrosion are assumed to be limited by brine inflow because they all consume water and have high reaction rates. The amounts of reactants are tabulated in Table SCR-3.

Table SCR-3. **Changes in Inventory Quantities from the CCA to the CRA-2014**

Inventory	**CCA**	**CRA-2004**	**CRA-2009**	**CRA-2014**
MgO (tons)	85,600[a]	72,760 (because of the elimination of mini-sacks)[a]	59,385[e]	51,430[h]
Cellulosics (tons)	5,940[b]	8,120[c]	8,907[f]	5,127[i]
Plastics (tons)	3,740[b]	8,120[c]	10,180[f]	10,487[i]
Rubber (tons)	1,100[b]	1,960[c]	1,885[f]	1,379[i]
Aluminum alloys (tons)	1,980[b]	1,960[c]	2,030[f]	504[i]
Cement (tons)	8,540[b]	9,971[d]	13,888[g]	11872[j]

[a] U.S. DOE (U.S. DOE 2000a)

[b] U.S. DOE (U.S. DOE 1996b). Only CH-TRU wastes are considered. Total volume of CH-TRU wastes is 1.1×10^5 m^3. This is not scaled to WIPP disposal volume.

[c] Appendix DATA-2004, Attachment F. Only CH-TRU wastes are considered. Total volume of CH-TRU waste is 1.4×10^5 m^3. This is not scaled to WIPP disposal volume.

[d] This estimate is derived from data in Leigh (Leigh 2003) includes both reacted and unreacted cement. (1.2×10^7 kg $\times$ $1.4 \times 10^5/168485/1000$ kg/ton = 9971 tons cement).

[e] This estimate is derived by assuming that Panel 1 has an MgO excess factor of 1.95, three panel equivalents have a 1.67 excess factor, and the remaining 6 panel equivalents have a 1.2 excess factor, resulting in a 1.416 projected excess factor for a full repository. The projected excess factor is then multiplied by the equivalent cellulose value of 28,098 × (40.3/27) (the MgO molar ratio).

[f] This value is derived using material densities reported in Leigh et al. (Leigh et al. 2005b) ,and total CH-TRU waste volume (1.45×10^5 m^3 reported in Leigh et al. (Leigh et al. 2005a)).

[g] This value is derived from data in Leigh (Leigh 2003) and Leigh et al. (Leigh et al. 2005a). ((1.2×10^7 kg) × 39/29 × (1.45×10^5)/168485/1000 kg/ton = 13,888 tons cement).

[h] This estimate is derived by assuming that Panel 1 has an MgO excess factor of 1.95, three panel equivalents have a 1.67 excess factor, and the remaining 6 panel equivalents have a 1.2 excess factor, resulting in a 1.416 projected excess factor for a full repository. The projected excess factor is then multiplied by the equivalent cellulose value of 24,334 × (40.3/27) (the MgO molar ratio).

[i] This value is derived from Van Soest (Van Soest 2012) and contains CH, RH, packaging, and emplacement materials.

[j] This value is derived from Van Soest (Van Soest 2012) and contains reacted and unreacted cements for both CH and RH wastes.

Similarly, MgO carbonation, which consumes CO_2, is limited by CO_2 generation from microbial degradation. Given a biodegradation rate constant, the total CO_2 generated per yr is proportional to the total quantity of biodegradable materials in the repository. Using the computational methods in Wang and Brush (Wang and Brush 1996a and Wang and Brush 1996b), the inventory of biodegradable materials has been changed from 23,884 (8,120 + 1.7 × 8,120 + 1,960) tons for the CRA-2004[1] to 28,098 (8,907 + 1.7 × 10,180 + 1,885) tons of equivalent cellulosics for the CRA-2009.[1] For the CRA-2014, this value changes to 24,334 (5,127 + 1.7 × 10,487 + 1,379) tons of equivalent cellulosics. This decrease in biodegradable materials corresponds to a proportional decrease in CO_2 generation, all other factors (such as brine saturation) being equal. For MgO carbonation and microbial degradation, the calculated temperature rises have been updated for the changes in both microbial gas generation and waste inventory and are presented in Table SCR-4.

Temperature rises (°C) by exothermic reactions are revised as follows:

CCA conditions following a drilling event show that Al corrosion could, at most, result in a short-lived (two yrs) temperature increase of about 6 °C (10.8 °F) above ambient room temperature (about 27 °C (80 °F)) (Bennett et al. 1996). A temperature rise of 6 °C (10.8 °F) represented the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Revised maximum temperature rises by exothermic reactions for CRA-2014 are still less than 12 ºC (22 °F) (as shown in Table SCR-4). Such small temperature changes cannot affect material properties. Thus, thermal effects on material properties in the repository have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Table SCR-4. CCA and CRA Exothermic Temperature Rises

Reactant	CCA[a]	CRA-2004[a]	CRA-2009[a]	CRA-2014[a]
Mgo hydration	< 4.5	< 4.7	< 4.2	< 3.9
Mgo carbonation	< 0.6	< 0.7	< 0.6	< 0.6
Microbial degradation	< 0.8	< 1.4	< 1.5	< 1.4
Aluminum corrosion	< 6.0	< 6.8	< 6.9	< 3.4
Cement hydration	< 2.0	< 2.5	< 3.0	< 2.7

[a] All values are in degrees Celsius.

All potential sources of heat and elevated temperature have been evaluated and found not to produce high enough temperature changes to affect the repository's performance. Sources of heat within the repository include radioactive decay and exothermic chemical reactions such as backfill hydration and metal corrosion. The rates of these exothermic reactions are limited by the availability of brine in the repository. In general, the various sources of heat do not appear to be great enough to jeopardize the performance of the disposal system.

SCR-6.3.5 Mechanical Effects on Material Properties

SCR-6.3.5.1

FEP Numbers: W32, W36, W37, W39, W113, and W114

FEP Titles: *Consolidation of Waste* (W32)
Consolidation of Shaft Seals (W36)

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[1] The 1.7 molar conversion rate for plastic is based on analyses presented in Wang and Brush (1996a and 1996b).

Mechanical Degradation of Shaft Seals (W37)
Underground Boreholes (W39)
Consolidation of Panel Closures (W113)
Mechanical Degradation of Panel Closures (W114)

SCR-6.3.5.1.1 Screening Decision: UP

Consolidation of Waste is accounted for in PA calculations. Consolidation of Shaft Seals and Panel Closures and Mechanical Degradation of Shaft Seals and Panel Closures are accounted for in PA calculations. Flow through isolated, unsealed Underground Boreholes is accounted for in PA calculations.

SCR-6.3.5.1.2 Summary of New Information

The descriptions and screening arguments for FEPs W113 *Consolidation of Panel Closures* and W114 *Mechanical Degradation of Panel Closures* will be affected by the planned ROM salt PCS. These repository components will continue to be screened into PA calculations (UP), but their implementation will change as a result of new parameter values necessary to represent the expected physical properties and characteristics of the ROM salt PCS. No other changes are required.

SCR-6.3.5.1.3 Screening Argument

Consolidation of waste is accounted for in PA calculations in the modeling of creep closure of the disposal room (Appendix PA-2014, Section PA-4.2.3).

Consolidation of shaft seals, consolidation of the ROM salt PCS, mechanical degradation of shaft seals, and mechanical degradation of panel closures are accounted for in PA calculations through the permeability ranges assumed for the seal and closure systems (Appendix PA-2014, Section PA-4.2.7 and Section PA-4.2.8).

The site investigation program has also involved the drilling of boreholes from within the excavated part of the repository. Following their use for monitoring or other purposes, these underground boreholes will be sealed where practical, and salt creep will also serve to consolidate the seals and to close the boreholes. Any boreholes that remain unsealed will connect the repository to anhydrite interbeds within the Salado, and thus provide potential pathways for radionuclide transport. PA calculations account for fluid flow to and from the interbeds by assuming that the DRZ has a permanently enhanced permeability that allows flow of repository brines into specific anhydrite layers and interbeds. This treatment is also considered to account for the effects of any unsealed boreholes.

SCR-6.3.5.2 **FEP Number:** W33 **FEP Title:** *Movement of Containers*

SCR-6.3.5.2.1 Screening Decision: SO-C

Movement of Containers has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3.5.2.2 Summary of New Information

The FEP description has been updated to reflect new waste inventory data for the CRA-2014. Waste densities have decreased slightly since the CRA-2009. This inventory change has no impact upon the screening argument and decision for this FEP.

SCR-6.3.5.2.3 Screening Argument

Movement of waste containers placed in salt may occur as a result of two buoyancy mechanisms (Dawson and Tillerson 1978): (1) the density contrast between the waste container and the surrounding salt, and (2) the temperature contrast between a salt volume that includes a heat source and the surrounding unheated salt. When the density of the waste container is greater than the density of the surrounding salt, the container sinks relative to the salt, whereas when the salt density is greater than the container density, the container rises relative to the salt. Similarly, when a discrete volume of salt within a large salt mass is heated, the heat raises the temperature of the discrete volume above that of the surrounding salt, thereby inducing density contrasts and buoyant forces that initiate upward flow of the heated salt volume. In a repository setting, the source of the heat may be radioactive decay of the waste itself or exothermic reactions of the backfill materials and waste constituents, e.g., MgO hydration, MgO carbonation, Al corrosion, cement hydration, and calcium oxide hydration.

For the CCA, the density of the compacted waste and the grain density of the halite in the Salado were assumed to be 2,000 kg/m^3 and 2,163 kg/m^3, respectively. Because this density contrast is small, the movement of containers relative to the salt was considered minimal, particularly when drag forces on the waste containers were also considered. In addition, vertical movement initiated in response to thermally induced density changes for high-level waste containers of a similar density to those at the WIPP were calculated to be approximately 0.35 m (1.1 ft) (Dawson and Tillerson 1978, p. 22). This calculated movement was considered conservative, given that containers at the WIPP will generate much less heat and will, therefore, move less. As a result, container movement was eliminated from PA calculations on the basis of low consequences to the performance of the disposal system.

The calculations performed for the DOE (U.S. DOE 1996a) were based on estimates of the waste inventory. However, with the initiation of waste disposal, actual waste inventory is tracked and future waste stream inventories have been refined. Based on an evaluation of these data, two factors may affect the conclusions reached in U.S. DOE (U.S. DOE 1996a) concerning container movement.

The first factor is changes in density of the waste form. According to CRA-2009 inventory data (Leigh et al. 2005a), the waste density has changed only slightly since that anticipated for the CCA. Most recent inventory data provided in Van Soest (Van Soest 2012) show slight decreases in overall waste densities (see Van Soest 2012, Table 6-3). Some future waste streams may, however, be more highly compacted, perhaps having a density roughly three times greater than that assumed in the CCA, while others may be less dense. In calculations of container movement, Dawson and Tillerson (Dawson and Tillerson 1978, p. 22) varied container density by nearly a factor of 3 (from 2,000 kg/m^3 (125 lb/ft^3) to 5,800 kg/m^3 (362 lb/ft^3)) and found that an individual dense container could move vertically as much as about 28 m (92 ft). Given the geologic environment of the WIPP, a container would likely encounter a dense stiff unit (such as an anhydrite stringer) that would arrest further movement far short of this upper bound; however, because of the massive thickness of the Salado salt, even a movement of 28 m (92 ft) would have little impact on performance.

The second inventory factor that could affect container movement is the composition of the waste (and chemical buffer) relative to its heat production. Radioactive decay, nuclear criticality, and exothermic reactions are three possible sources of heat in the WIPP repository. According to Kicker and Zeitler (Kicker and Zeitler 2013) the TRU radionuclide inventory has decreased from 3.44×10^6 Ci reported in the CCA, to 2.48×10^6 Ci in the CRA-2004, to 2.32×10^6 Ci in the CRA-2009 to 2.06×10^6 Ci in the CRA-2014. Such a small change will not result in a significant deviation from the possible temperature rise predicted in the CCA. Additionally, and as shown in Section SCR-6.3.4.1 (FEPs W72 and W73), temperature rises from exothermic reactions are quite small (see Table SCR-4). Note that the revised maximum temperature increases caused by exothermic reactions are still less than 12 °C (22 °F).

Based on the small differences between the temperature and density assumed in the CCA and those determined using new inventory data (Van Soest 2012; Kicker and Zeitler 2013), the conclusion about the importance of container movement reported in the CCA will not be affected, even when more highly compacted future waste streams are considered. The effects of the revised maximum temperature rise and higher-density future waste streams on container movement are competing factors (high-density waste will sink, whereas the higher-temperature waste-salt volume will rise) that may result in even less movement. Therefore, movement of waste containers has been eliminated from PA calculations on the basis of low consequence.

SCR-6.3.5.3 **FEP Number:** W34
FEP Title: *Container Integrity*

SCR-6.3.5.3.1 Screening Decision: SO-C Beneficial

Container Integrity has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.3.5.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.3.5.3.3 Screening Argument

Container integrity is required only for waste transportation. Past PA calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 yrs (see, for example, Helton et al. 1998). In addition, it is assumed in both CCA and CRA-2004 calculations that there is no microbial degradation of plastic container materials in 75% of PA realizations (Wang and Brush 1996). All these undegraded container materials will (1) prevent the contact between brine and radionuclides; and (2) decrease the rate and extent of radionuclide transport because of high tortuosity along the flow pathways and, as a result, increase opportunities for metallic iron and corrosion products to beneficially reduce radionuclides to lower oxidation states. Therefore, container integrity can be eliminated on the basis of its beneficial effect on retarding radionuclide transport. PA assumes instantaneous container failure and waste dissolution according to the source-term model.

SCR-6.3.5.4 FEP Number: W35
FEP Title: *Mechanical Effects of Backfill*

SCR-6.3.5.4.1 Screening Decision: SO-C

The *Mechanical Effects of Backfill* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3.5.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.3.5.4.3 Screening Argument

The chemical conditioners or backfill added to the disposal room will act to resist creep closure. However, calculations have shown that because of the high porosity and low stiffness of the waste and the high waste to potential backfill volume, inclusion of backfill does not significantly decrease the total subsidence in the waste emplacement area or disposal room (Westinghouse 1994). In 2001, the DOE eliminated MgO mini-sacks from the repository, reducing the total inventory from 85,600 short tons to 74,000 short tons, which reduced the potential backfill volume (U.S. EPA 2001). More recently, the required amount of MgO has been further reduced (Reyes 2008). Therefore, the mechanical effects of backfill have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.4 Subsurface Hydrological and Fluid Dynamic FEPs

SCR-6.4.1 Repository-Induced Flow

SCR-6.4.1.1 **FEP Numbers:** W40 and W41
FEP Titles: *Brine Inflow* (W40)
Wicking (W41)

SCR-6.4.1.1.1 Screening Decision: UP

Two-phase brine and gas flow and capillary rise (wicking) in the repository and the Salado are accounted for in PA calculations.

SCR-6.4.1.1.2 Summary of New Information

Expected repository conditions vary based on factors such as contents of the repository, brine present, elapsed time since closure and the most recent hypothetical intrusion. These factors (and others) are considered interdependent and represent the complex interactions that might prevail over time in the repository environment. These interactions are accounted for in the Chemical Conditions Conceptual Model. As part of their review of the CRA-2009, the EPA noted that the existing treatment for water balance within the repository could be improved to include additional chemical reactions that affect the water balance within the repository (U.S. EPA 2010b). As such, the CRA-2014 PA calculations will include an improved treatment of water balance. The main objective of refining the repository water balance is to include the major gas and brine producing and consuming reactions within the existing conceptual model. This change in the implementation of repository water balance is considered a model enhancement as it adds additional reactions (MgO hydration, and the carbonation of brucite to form hydromagnesite) that represent transitional compounds in the reaction path. While these two FEPs are not directly related to this change, this new information is provided for completeness. Also, because this change in implementation will occur downstream of the FEP screening process, these FEPs remain classified UP.

SCR-6.4.1.1.3 Screening Argument

Brine inflow to the repository may occur through the DRZ, impure halite, anhydrite layers, or clay layers. Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Two-phase flow of brine and gas in the repository and the Salado is accounted for in PA calculations (Appendix PA-2014, Section PA-4.2).

Capillary rise (or wicking) is a potential mechanism for liquid migration through unsaturated zones in the repository. Capillary rise in the waste material could affect gas generation rates, which are dependent on water availability. Potential releases caused by drilling intrusion are also influenced by brine saturations and therefore by wicking. Capillary rise is therefore accounted for in PA calculations (Appendix PA-2014, Section PA-4.2).

SCR-6.4.2 Effects of Gas Generation

SCR-6.4.2.1 **FEP Number:** W42
FEP Title: *Fluid Flow Due to Gas Production*

SCR-6.4.2.1.1 Screening Decision: UP

Fluid Flow Due to Gas Production in the repository and the Salado is accounted for in PA calculations.

SCR-6.4.2.1.2 Summary of New Information

Refinement in the implementation of water balance as described above in SCR-6.4.1.1.2 will also affect the implementation of this FEP through the availability of water. Also, gas generation rates due to iron corrosion have been modified as a result of newly acquired experimental data (Roselle 2013) (see section SCR-6.3.2.1.2). Because this change is a refinement of a process already screened in, no other changes are necessary to this FEP. It remains classified UP.

SCR-6.4.2.1.3 Screening Argument

Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Gas may flow from the repository through the DRZ, impure halite, anhydrite layers, or clay layers. The amount of water available for reactions and microbial activity will impact the amounts and types of gases produced (W44 through W55, Section SCR-6.5.1.1, Section SCR-6.5.1.2, Section SCR-6.5.1.3, Section SCR-6.5.1.4, Section SCR-6.5.1.5, Section SCR-6.5.1.6, Section SCR-6.5.1.7, Section SCR-6.5.1.8, and Section SCR-6.5.1.9). Gas generation rates, and therefore repository pressure, may change as the water content of the repository changes. Pressure changes and fluid flow due to gas production in the repository and the Salado are accounted for in PA calculations through modeling the two-phase flow (Appendix PA-2014, Section PA-4.2).

SCR-6.4.3 Thermal Effects

SCR-6.4.3.1 **FEP Number:** W43
FEP Title: *Convection*

SCR-6.4.3.1.1 Screening Decision: SO-C

Convection has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.4.3.1.2 Summary of New Information

Planned SDI experiments as detailed in Patterson (Patterson 2011) or the SDDI project (Franco 2012) will place heaters in newly excavated tunnels in the northern experimental region of the WIPP. Mining has been completed, but heater tests have not yet commenced. An evaluation conducted by Kuhlman (Kuhlman 2011) for the SDI PCN shows that any thermal pulse from these experiments will be very minimal, on the order of 0.02 °C or less. Therefore, the screening argument and decision for this FEP is unaffected by the conduct of these experiments.

SCR-6.4.3.1.3 Screening Argument

Temperature differentials in the repository could initiate convection. The resulting thermally induced brine flow or thermally-induced, two-phase flow could influence contaminant transport. Thermal gradients in the disposal rooms could potentially drive the movement of water vapor. For example, temperature increases around waste located at the edges of the rooms could cause evaporation of water entering from the DRZ. This water vapor could condense on cooler waste containers in the rooms and could contribute to brine formation, corrosion, and gas generation.

The characteristic velocity, *Vi*, for convective flow of fluid component *I* in an unsaturated porous medium is given by (from Hicks 1996)

$$V_i \approx -\frac{k_i}{\mu_i}\left(\alpha_i \rho_{i0} g \Delta T\right) \tag{SCR.11}$$

where α_i (per degree Kelvin) is the coefficient of expansion of the i^{th} component, k_i is the intrinsic permeability (m^2), μ_i is the fluid viscosity (pascal second), ρ_{i0} (kg/m^3) is the fluid density at a reference point, g is the acceleration due to gravity, and ΔT is the change in temperature. This velocity may be evaluated for the brine and gas phases expected in the waste disposal region.

For a temperature increase of 10 °C (18 °F), the characteristic velocity for convective flow of brine in the DRZ around the concrete shaft seals is approximately 7×10^{-4} m (2.3×10^{-3} ft) per yr (2×10^{-11} m (6.6×10^{-11} ft) per second), and the characteristic velocity for convective flow of gas in the DRZ is approximately 1×10^{-3} m (3.2×10^{-3} ft) per yr (3×10^{-11} m (9.8×10^{-11} ft) per second) (Hicks 1996). For a temperature increase of 25 °C (45 °F), the characteristic velocity for convective flow of brine in the concrete seals is approximately 2×10^{-7} m (6.5×10^{-7} ft) per yr (6×10^{-15} m (1.9×10^{-14} ft) per second), and the characteristic velocity for convective flow of gas in the concrete seals is approximately 3×10^{-7} m (9.8×10^{-7} ft) per yr (8×10^{-15} m (2.6×10^{-4} ft) per second) (Hicks 1996). These values of Darcy velocity are much smaller than the expected values associated with brine inflow to the disposal rooms resulting from gas generation. In addition, the buoyancy forces generated by smaller temperature contrasts in the DRZ, resulting from backfill and radioactive decay will be short-lived and insignificant compared to the other driving forces for fluid flow. In summary, temperature changes in the disposal system will not cause significant thermal convection. Furthermore, the induced temperature gradients will be insufficient to generate water vapor and drive significant moisture migration.

The viscosity of pure water decreases by about 19% over a temperature range of between 27 °C (80 °F) and 38 °C (100 °F) (Batchelor 1973, p. 596). Although at a temperature of 27 °C (80 °F), the viscosity of Salado brine is about twice that of pure water (Rechard et al. 1990, p. A-19), the magnitude of the variation in brine viscosity between 27 °C (80 °F) and 38 °C (100 °F) will be similar to the magnitude of the variation in viscosity of pure water. The viscosity of air over this temperature range varies by less than 7% (Batchelor 1973, p. 594) and the viscosity of gas in the waste disposal region over this temperature range is also likely to vary by less than 7%. The Darcy fluid flow velocity for a porous medium is inversely proportional to the fluid viscosity. Thus, increases in brine and gas flow rates may occur as a result of viscosity variations in the vicinity of the concrete shaft seals. However, these viscosity variations will persist only for a short period in which temperatures are elevated, and, thus, the expected variations in brine and gas viscosity in the waste disposal region will not significantly affect the long-term performance of the disposal system.

For the CCA conditions following a drilling event, Al corrosion could, at most, result in a short-lived (two yrs) temperature increase of about 6 °C (10.8 °F). A temperature rise of 6 °C (10.8 °F) represented the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Revised maximum temperature rises by exothermic reactions for CRA-2014 are still less than 12 °C (22 °F) (as shown in Table SCR-4). Such small temperature changes cannot affect material properties and thermally induced flow.

In summary, temperature changes in the disposal system will not cause significant thermally induced two-phase flow. Thermal convection has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5 Geochemical and Chemical FEPs

SCR-6.5.1 Gas Generation

SCR-6.5.1.1

FEP Numbers: W44, W45, and W48
FEP Titles: *Degradation of Organic Material* (W44)
Effects of Temperature on Microbial Gas Generation (W45)
Effects of Biofilms on Microbial Gas Generation (W48)

SCR-6.5.1.1.1 Screening Decision: UP

Microbial gas generation from Degradation of Organic Material is accounted for in PA calculations, and the Effects of Temperature on Microbial Gas Generation and the Effects of Biofilm Formation on Microbial Gas Generation are incorporated in the gas generation rates used.

SCR-6.5.1.1.2 Summary of New Information

These FEPs have been updated to be consistent with the latest inventory information and information resulting from an EPA request on the CRA-2009 (Kelly 2009). Clarifying statements have been added that reflect DOE’s response to the EPA’s request. The screening argument and decision are not affected by the updated information.

SCR-6.5.1.1.3 Screening Argument

Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO_2 and CH_4 with minor amounts of nitrogen oxide, nitrogen, and hydrogen sulfide. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. Microbial gas generation from degradation of organic material is accounted for in PA calculations. The latest data on microbial ecology at WIPP is given in Appendix SOTERM-2.4.1 and Swanson et al. (Swanson et al. 2012).

The following subsections discuss the effects of temperature, pressure, radiation, and biofilms on gas production rates via their control of microbial gas generation processes.

SCR-6.5.1.1.3.1 Effects of Temperature on Microbial Gas Generation

Calculations and experimental studies of induced temperature distributions within the repository have been undertaken and are described in FEPs W29, W30, and W31 (Section SCR-6.3.4.1). Numerical analysis suggests that the average temperature increase in the WIPP repository caused by radioactive decay of the emplaced CH-TRU and RH-TRU waste is likely to be less than 2 °C (3.6 °F) (FEP W13).

Temperature increases resulting from exothermic reactions are discussed in FEPs W72 and W73 (Section SCR-6.3.4.1). Potentially the most significant exothermic reactions are concrete hydration, backfill hydration, and aluminum corrosion. Hydration of the seal concrete could raise the temperature of the concrete to approximately 53 °C (127 °F) and that of the surrounding salt to approximately 38 °C (100 °F) one week after seal emplacement (W73).

As discussed in FEPs W72 and W73 (Section SCR-6.3.4.1), the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 3.9 °C (7.0 °F), resulting from brine inflow following a drilling intrusion into a waste disposal panel. Note that AICs will prevent drilling within the controlled area for 100 yrs after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have decreased to close to initial values.

Under similar conditions following a drilling event, Al corrosion could, at most, result in a short-lived (two yrs) temperature rise of about 3.4 °C (6.1 °F) (see W72). These calculated maximum heat generation rates resulting from Al corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 12 °C (22 °F) represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Additionally, these reactions would be transient in nature and will not persist for long periods of time.

Relatively few data exist on the effects of temperature on microbial gas generation under expected WIPP conditions. Molecke (Molecke 1979, p. 4) summarized microbial gas generation rates observed during a range of experiments. Increases in temperature from ambient up to 40 °C (104 °F) or 50 °C (122 °F) were reported to increase gas production, mainly via the degradation of cellulosic waste under either aerobic or anaerobic conditions (Molecke 1979, p. 7). Above 70 °C (158 °F), however, gas generation rates were generally observed to decrease. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates, representing likely states within the repository. Gas generation rates were presented as ranges with upper and lower bounds as estimates of uncertainty (Molecke 1979, p. 7). Molecke's work evaluated gas-generation rates over a range of temperatures, including those significantly higher than expected in the WIPP (up to 70 °C [158 °F]). Later experiments reported by Francis and Gillow (Francis and Gillow 1994) support the gas generation rate data reported by Molecke (Molecke 1979). These experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. These experiments were carried out at a temperature of 30 °C (86 °F). Gas generation rates used in the PA calculations are described in Appendix PA-2014, Section PA-4.2.5. The effects of temperature on microbial gas generation are implicitly incorporated in the gas generation rates used.

SCR-6.5.1.1.3.2 Effects of Biofilms on Microbial Gas Generation

The location of microbial activity within the repository is likely to be controlled by the availability of substrates and nutrients. Biofilms may develop on surfaces where nutrients are concentrated. They consist of one or more layers of cells with extracellular polymeric material, and serve to maintain an optimum environment for growth. Within such a biofilm ecosystem, nutrient retention and recycling maximize microbe numbers on the surface (see, for example, Stroes-Gascoyne and West 1994, pp. 9–10).

Biofilms can form on almost any moist surface, but their development is likely to be restricted in porous materials. Even so, their development is possible at locations throughout the disposal system. The effects of biofilms on microbial gas generation may affect disposal system performance through control of microbial population size and their effects on radionuclide transport.

Molecke (Molecke 1979, p. 4) summarized microbial gas generation rates observed during a range of experimental studies. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates representing likely states within the repository. However, the effect of biofilm formation in these experiments was uncertain. Molecke (Molecke 1979, p. 7), presented gas generation rates as ranges, with upper and lower bounds as estimates of uncertainty. Later experiments reported by Francis and Gillow (Francis and Gillow 1994) support the gas generation rate data reported by Molecke (Molecke 1979). Their experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. Under the more favorable conditions for microbial growth established during the experiments, the development of populations of halophilic microbes and associated biofilms was evidenced by observation of an extracellular, carotenoid pigment, bacterioruberin, in the culture bottles (Francis and Gillow 1994, p. 59). Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Appendix PA-2014, Section PA-4.2.5. The effects of biofilms on microbial gas generation rates are implicitly incorporated in the gas generation rates.

Biofilms may also influence contaminant transport rates through their capacity to retain and thus retard both the microbes themselves and radionuclides. This effect is not accounted for in PA calculations, but is considered potentially beneficial to calculated disposal system performance. Microbial transport is discussed in Section SCR-6.6.3.1.

SCR-6.5.1.2 **FEP Number:** W46 **FEP Title:** *Effects of Pressure on Microbial Gas Generation*

SCR-6.5.1.2.1 Screening Decision: SO-C

The *Effects of Pressure on Microbial Gas Generation* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.5.1.2.3 Screening Argument

Directly relevant to WIPP conditions, the gas generation experiments with actual waste components at Argonne National Laboratory provide no indication of any enhancement of pressured nitrogen atmosphere (2,150 pounds per square inch absolute [psia]) on microbial gas generation (Felicione et al. 2001). In addition, microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials in the repository, will produce mainly CO_2 and CH_4 with minor amounts of nitrogen oxide, nitrogen, and hydrogen sulfide. The accumulation of these gaseous species will contribute to the total pressure in the repository. Increases in the partial pressures of these reaction products could potentially limit gas generation reactions. However, such an effect is not taken into account in the WIPP PA calculations. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. Microbial gas generation from degradation of organic material is accounted for in PA calculations.

Chemical reactions may occur depending on, among other things, the concentrations of available reactants, the presence of catalysts and the accumulation of reaction products, the biological activity, and the prevailing conditions (for example, temperature and pressure). Reactions that involve the production or consumption of gases are often particularly influenced by pressure because of the high molar volume of gases. The effect of high total pressures on chemical reactions is generally to reduce or limit further gas generation.

Few data exist from which the effects of pressure on microbial gas generation reactions that may occur in the WIPP can be assessed and quantified. Studies of microbial activity in deep-sea environments (for example, Kato et al. 1994, p. 94) suggest that microbial gas generation reactions are less likely to be limited by increasing pressures in the disposal rooms than are inorganic gas generation reactions (for example, corrosion). Consequently, the effects of pressure on microbial gas generation have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.3 **FEP Number:** W47
FEP Title: *Effects of Radiation on Microbial Gas Generation*

SCR-6.5.1.3.1 Screening Decision: SO-C

The *Effects of Radiation on Microbial Gas Generation* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.3.2 Summary of New Information

The FEP screening argument has been updated to reflect the radionuclide inventory used for CRA-2009 calculations, although the screening decision has not changed.

SCR-6.5.1.3.3 Screening Argument

Radiation may slow down microbial gas generation rates, but such an effect is not taken into account in the WIPP PA calculations. According to the inventory data presented in Leigh and Trone (Leigh and Trone 2005), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 Ci reported in the CCA, to 2.48×10^6 Ci in the CRA-2004, to 2.32×10^6 Ci in the CRA-2009, to 2.06×10^6 Ci for the CRA-2014 (Kicker and Zeitler 2013). This decrease will not affect the original screening argument.

Experiments investigating microbial gas generation rates suggest that the effects of alpha radiation from TRU waste is not likely to have significant effects on microbial activity (Barnhart et al. 1980; Francis 1985). Consequently, the effects of radiation on microbial gas generation have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.4 **FEP Numbers:** W49 and W51
FEP Titles: *Gases from Metal Corrosion*
Chemical Effects of Corrosion

SCR-6.5.1.4.1 Screening Decision: UP

Gas generation from metal corrosion is accounted for in PA calculations, and the effects of chemical changes from metal corrosion are incorporated in the gas generation rates used.

SCR-6.5.1.4.2 Summary of New Information

Metals present in the waste and waste containers have been updated for the CRA-2014 in Van Soest (Van Soest 2012). Iron corrosion experiments (Wall and Enos 2006) have been completed since the CRA-2009 that provide new corrosion rates for expected WIPP-relevant conditions (Roselle 2013). These rates are implemented with a new parameter distribution type and values for the parameter STEEL:CORRMCO2. This parametric change does not affect the screening argument, decision, or the implementation of gas generation within PA models.

SCR-6.5.1.4.3 Screening Argument

Oxic corrosion of waste drums and metallic waste will occur at early times following closure of the repository and will deplete its oxygen content. Anoxic corrosion will follow the oxic phase and will produce hydrogen while consuming water. Gases from metal corrosion are accounted for in PA calculations.

The predominant chemical effect of corrosion reactions on the environment of disposal rooms will be to lower the oxidation state of the brines and maintain reducing conditions.

Molecke (Molecke 1979, p. 4) summarized gas generation rates that were observed during a range of experiments. The experiments were conducted over a range of temperatures and chemical conditions representing likely states within the repository. Later experiments reported by Telander and Westerman (Telander and Westerman 1993) support the gas generation rate data reported by Molecke (Molecke 1979). Their experiments investigated gas generation from corrosion under a wide range of possible conditions in the repository. The studies included corrosion of low-carbon steel waste packaging materials in synthetic brines, representative of intergranular Salado brines at the repository horizon, under anoxic (reducing) conditions.

Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Appendix PA-2014, Section PA-4.2.5. Recently completed iron corrosion experiments were analyzed by Roselle (Roselle 2013) and result in new iron corrosion rates which in turn affect the rate of gas generation from this process. The effects of chemical changes from metal corrosion are, therefore, accounted for in PA calculations.

SCR-6.5.1.5 FEP Number: W50 FEP Title: *Galvanic Coupling (within the repository)*

SCR-6.5.1.5.1 Screening Decision: SO-C

The effects of *Galvanic Coupling* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.5.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.5.1.5.3 Screening Argument

Galvanic coupling (i.e., establishing an electrical current through chemical processes) could lead to the propagation of electric potential gradients between metals in the waste form, canisters, and other metals external to the waste form, potentially influencing corrosion processes, gas generation rates, and chemical migration.

Metallic ore bodies external to the repository are nonexistent (see the CCA, Appendix GCR) and therefore galvanic coupling between the waste and metals external to the repository would not occur. However, a variety of metals will be present within the repository as waste metals and containers, creating a potential for formation of galvanic cells over short distances. As an example, the presence of copper could influence rates of hydrogen gas production resulting from the corrosion of iron. The interactions between metals depend upon their physical disposition and the prevailing solution conditions, including pH and salinity. Good physical and electrical contact between the metals is critical to the establishment of galvanic cells.

Consequently, given the preponderance of iron over other metals within the repository and the likely passivation of many nonferrous materials, the influence of these electrochemical interactions on corrosion, and therefore on gas generation, is expected to be minimal. Therefore, the effects of galvanic coupling have been eliminated from PA calculations on the basis of low consequence.

SCR-6.5.1.6 **FEP Number:** W52
FEP Title: *Radiolysis of Brine*

SCR-6.5.1.6.1 Screening Decision: SO-C

Gas generation from *Radiolysis of Brine* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.6.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.5.1.6.3 Screening Argument

Radiolysis of brine in the WIPP disposal rooms, and of water in the waste, will lead to the production of gases and may significantly affect the oxygen content of the rooms. This, in turn, will affect the prevailing chemical conditions and potentially the concentrations of radionuclides that may be mobilized in the brines.

The overall reaction for the radiolysis of water in the waste and brine is

$$H_2O \rightarrow H_2 + \tfrac{1}{2} O_2. \qquad \text{(SCR.12)}$$

However, the production of intermediate oxygen-bearing species that may subsequently undergo reduction will lead to reduced oxygen gas yields. The remainder of this section is concerned with the physical effects of gas generation by radiolysis of brine.

Reed et al. (Reed et al. 1993) studied radiolytic gas generation during experiments lasting between 155 and 182 days. These experiments involved both synthetic brines similar to those sampled from the Salado at the WIPP repository horizon, and brines occurring in reservoirs in the Castile, as well as real brines sampled from the Salado in the repository workings. The brines were spiked with ^{239}Pu(VI) at concentrations between 6.9×10^{-9} and 3.4×10^{-4} molal. During these relatively short-term experiments, hydrogen gas was observed as the product of radiolysis. Oxygen gas was not observed; this was attributed to the formation of intermediate oxygen-bearing species. However, given sufficient exposure to alpha-emission, oxygen production may reach 50% that of hydrogen.

An estimate of the potential rate of gas generation caused by the radiolysis of brine, R_{RAD}, can be made by making the following assumptions:

- Gas production occurs following the reaction above, so that 1.5 moles of gas are generated for each mole of water consumed
- Gas production occurs as a result of the alpha decay of ^{239}Pu
- ^{239}Pu concentrations in the disposal room brines are controlled by solubility equilibria
- All of the dissolved Pu is ^{239}Pu

R_{RAD} is then given by

$$R_{RAD} = \frac{Y_g C_{Pu} SA_{Pu} \overline{E}_\alpha V_B}{N_D N_A} \tag{SCR.13}$$

$$R_{RAD} = \frac{\left(\frac{1.5\text{ molecule gas}}{\text{molecule H}_2\text{O}}\right)\left(3.15\times10^{7}\ \frac{\text{s}}{\text{yr}}\right)\left(3\times10^{-4}\ \frac{\text{mol}}{\text{L}}\right)\left(5.42\times10^{11}\ \frac{\text{Bq}}{\text{mol}}\right)\left(5.15\times10^{6}\ \frac{\text{eV}}{\text{dis}}\right)\left(\frac{1.5\text{ H}_2\text{O}}{100\text{ eV}}\right)\left(4.36\times10^{8}\text{L}\right)}{\left(8\times10^{5}\text{ drums}\right)\left(6.022\times10^{23}\ \frac{\text{molecules}}{\text{mole}}\right)}$$

$$= 0.533\text{ mol/drum/yr}$$

(SCR.14)

Y_g = radiolytic gas yield, in number of moles of gas produced per number of water molecules consumed
C_{Pu} = maximum dissolved concentration of plutonium (molar)
SA_{Pu} = specific activity of ^{239}Pu (5.42×10^{11} becquerels (Bq) per mole)
$\overline{E}_\alpha$ = average energy of α-particles emitted during ^{239}Pu decay (5.15×10^{6} eV)

G = number of water molecules split per 100 eV of energy transferred from alpha-particles
V_B = volume of brine in the repository (L)
N_D = number of CH-TRU drums in the repository (~8 ×10^5)
N_A = Avogadro constant (6.022 × 10^{23} molecules per mole)

The value of *G* used in this calculation has been set at 0.015, the upper limit of the range of values observed (0.011 to 0.015) during experimental studies of the effects of radiation on WIPP brines (Reed et al. 1993). A maximum estimate of the volume of brine that could potentially be present in the disposal region has been made from its excavated volume of 436,000 m^3 (520,266 cubic yards [yd^3]). This estimate, in particular, is considered to be highly conservative because it makes no allowance for creep closure of the excavation, or for the volume of waste and backfill that will be emplaced, and takes no account of factors that may limit brine inflow. These parameter values lead to an estimate of the potential rate of gas production caused by the radiolysis of brine of 0.6 moles per drum per yr or less.

Assuming ideal gas behavior and repository conditions of 30 °C (86 °F) and 14.8 MPa (lithostatic pressure), this is equivalent to approximately 6.8×10^4 L (1.8×10^4 gal) per yr.

Potential gas production rates from other processes that will occur in the repository are significantly greater than this. For example, under water-saturated conditions, microbial degradation of cellulosic waste has the potential to yield between 1.3×10^6 and 3.8×10^7 L (3.4×10^5 and 1.0×10^7 gal) per yr; anoxic corrosion of steels has the potential to yield up to 6.3×10^5 L (1.6×10^5 gal) per yr.

In addition to the assessment of the potential rate of gas generation by radiolysis of brine given above, a study of the likely consequences on disposal system performance has been undertaken by Vaughn et al. (Vaughn et al. 1995). A model was implemented in BRAGFLO to estimate radiolytic gas generation in the disposal region according to the equation above.

A set of BRAGFLO simulations was performed to assess the magnitude of the influence of the radiolysis of brine on contaminant migration to the accessible environment. The calculations considered radiolysis of water by 15 isotopes of Th, Pu, U, and Am. Conditional CCDFs of normalized contaminated brine releases to the Culebra via a human intrusion borehole and the shaft system, as well as releases to the subsurface boundary of the accessible environment via the Salado interbeds, were constructed and compared to the corresponding baseline CCDFs calculated excluding radiolysis. The comparisons indicated that radiolysis of brine does not significantly affect releases to the Culebra or the subsurface boundary of the accessible environment under disturbed or undisturbed conditions (Vaughn et al. 1995). Although the analysis of Vaughn et al. (Vaughn et al. 1995) used data that are different than those used in the PA calculations, estimates of total gas volumes in the repository are similar to those considered in the analysis performed by Vaughn et al. (Vaughn et al. 1995).

Therefore, gas generation by radiolysis of brine has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.7 FEP Number: W53
FEP Title: *Radiolysis of Cellulose*

SCR-6.5.1.7.1 Screening Decision: SO-C

Gas generation from *Radiolysis of Cellulose* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.7.2 Summary of New Information

This FEP has been updated with new inventory data related to cellulose content. Decreasing waste inventory values indicate that radiolysis of cellulose will not be a significant process. The screening argument and decision are not affected by this change in inventory information.

SCR-6.5.1.7.3 Screening Argument

Molecke (Molecke 1979) compared experimental data on gas production rates caused by radiolysis of cellulose and other waste materials with gas generation rates by other processes, including bacterial (microbial) waste degradation. The comparative gas generation rates reported by Molecke (Molecke 1979, p. 4) are given in terms of most probable ranges, using units of moles per yr per drum, for drums of 0.21 m^3 (0.27 yd^3) in volume. A most probable range of 0.005 to 0.011 moles per yr per drum is reported for gas generation caused by radiolysis of cellulosic material (Molecke 1979, p. 4). As a comparison, a most probable range of 0.0 to 5.5 moles per yr per drum is reported for gas generation by bacterial degradation of waste.

The data reported by Molecke (Molecke 1979) are consistent with more recent gas generation investigations made under the WIPP program, and indicate that radiolysis of cellulosic materials will generate significantly less gas than other gas generation processes. Gas generation from radiolysis of cellulosics therefore can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Radiolytic gas generation is controlled by the radioactivity of wastes and the waste properties. According to the new inventory presented in Leigh and Trone (Leigh and Trone 2005), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 Ci reported in the CCA, to 2.48×10^6 Ci in the CRA-2004, to 2.32×10^6 Ci in the CRA-2009 to 2.06×10^6 Ci in the CRA-2014 (Kicker and Zeitler 2013). Such decreasing activity levels imply that the radiolytic effects will be decreased from those presented in the CCA.

Radiolytic gas generation is also limited by transportation requirements, which state that the hydrogen generated in the innermost layer of confinement must be no more than 5% over 60 days (U.S. DOE 2000b). Thus, the maximum rate allowed for transportation is $0.21 \text{ m}^3/\text{drum} \times 5\% \times 1{,}000 \text{ L/m}^3/60 \text{ days} \times 365 \text{ days/yr} = 61 \text{ L/drum/yr}$, smaller than the maximum microbial gas generation rate. Note that this estimate is very conservative and the actual rates are even smaller. This result is consistent with the general consensus within the international research community that the effect of radiolytic gas generation on the long-term performance of a low/intermediate level waste repository is negligible (Rodwell et al. 1999).

SCR-6.5.1.8 FEP Number: W54
FEP Title: *Helium Gas Production*

SCR-6.5.1.8.1 Screening Decision: SO-C

Gas generation from helium production has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.8.2 Summary of New Information

The updated information for the WIPP disposal inventory indicates that the expected WIPP-scale radionuclide activity (2.06 million Ci of TRU isotopes) (Kicker and Zeitler 2013) is less than previously estimated in the Transuranic Waste Baseline Inventory Report, Revision 3 (U.S. DOE 1996b). Thus, the helium gas production argument for CRA-2014 is conservatively bounded by the CCA screening argument. The FEP screening argument and screening decision remain unchanged.

SCR-6.5.1.8.3 Screening Argument

Helium gas production will occur by the reduction of α-particles (helium nuclei) emitted from the waste. The maximum amount of helium that could be produced can be calculated from the number of α-particles generated during radioactive decay. The α-particles are converted to helium gas by the following reaction:

$$^{4}He^{2+} + 2e^{-} \rightarrow He(g) \qquad \text{(SCR.15)}$$

For the screening argument used in the CCA, the inventory *(I)* that may be emplaced in the repository is approximately 4.07 million Ci or 1.5×10^{17} Bq (see the CCA, Appendix BIR). Assuming that the inventory continues to yield α-particles at this rate throughout the 10,000-yr regulatory period, the maximum rate of helium gas produced (R_{He}) may be calculated from

$$R_{He} = \frac{I\left(\frac{1\ He\ atom}{\alpha - decay}\right)}{N_A} \qquad \text{(SCR.16)}$$

R_{He} is the rate of helium gas production in the repository (mole per second).

I is the waste inventory, 1.5×10^{17} Bq, assuming that 1 Bq is equal to 1 α-decay per second, and N_A is Avogadro's constant (6.022×10^{23} atoms per mole). These assumptions regarding the inventory lead to maximum estimates for helium production because some of the radionuclides will decay by beta and gamma emission.

R_{He} is approximately 5.5×10^{-7} moles per second based on an α-emitting inventory of 4.07 million Ci (much greater than current inventory estimates) (Kicker and Zeitler 2013). Assuming ideal gas behavior and repository conditions of 30 °C (86 °F) and 14.8 MPa or 146 atmospheres (lithostatic pressure) yields approximately 1.3 L (0.34 gal) per yr.

The effects of helium gas production have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.9 **FEP Number:** W55
FEP Title: *Radioactive Gases*

SCR-6.5.1.9.1 Screening Decision: SO-C

The formation and transport of *Radioactive Gases* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.9.2 Summary of New Information

This FEP has been updated with references to the latest inventory information.

SCR-6.5.1.9.3 Screening Argument

Based on the composition of the anticipated waste inventory, as described in Van Soest (Van Soest 2012), the radioactive gases that will be generated in the repository are radon (Rn) and ^{14}C-labeled CO_2 and CH_4.

Van Soest (Van Soest 2012) indicates that a small amount of ^{14}C (0.01 Ci) will be disposed in the WIPP. This amount is insignificant in comparison with the section 191.13 cumulative release limit for ^{14}C.

Notwithstanding this comparison, consideration of transport of radioactive gases could potentially be necessary in respect of the section 191.15 individual protection requirements. ^{14}C may partition into CO_2 and CH_4 formed during microbial degradation of cellulosic and other organic wastes (for example, rubbers and plastics). However, total fugacities of CO_2 in the repository are expected to be very low because of the action of the MgO backfill, which will lead to incorporation of CO_2 in solid magnesite. Similarly, interaction of CO_2 with cementitious wastes will limit CO_2 fugacities by the formation of solid calcium carbonate. Thus, because of the formation of solid carbonate phases in the repository, significant transport of ^{14}C as carbon dioxide-14 has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Potentially significant volumes of CH_4 may be produced during the microbial degradation of cellulosic waste. However, volumes of methane-14 will be small given the low total inventory of ^{14}C and the tendency of ^{14}C to be incorporated into solid carbonate phases in the repository. Therefore, although transport of ^{14}C could occur as methane-14, this effect has been eliminated from the current PA calculations on the basis of low consequence to the performance of the disposal system.

Rn gas will contain proportions of the alpha emitters ^{219}Rn, ^{220}Rn, and ^{222}Rn. All of these have short half-lives, but ^{222}Rn is potentially the most important because it is produced from the abundant waste isotope, ^{238}Pu, and because it has the longest half-life of the radon isotopes ($\approx$ 4 days). ^{222}Ra will exhibit secular equilibrium with its parent ^{226}Rn, which has a half-life of 1600 yrs. Consequently, ^{222}Rn will be produced throughout the 10,000-yr regulatory time period. Conservative analysis of the potential ^{222}Rn inventory suggests activities of less than 716 Ci at 10,000 yrs (Bennett 1996).

Direct comparison of the estimated level of ^{222}Rn activity with the release limits specified in section 191.13 cannot be made because the release limits do not cover radionuclides with half-lives less than 20 yrs. For this reason, production of Rn gas can be eliminated from the PA calculations on regulatory grounds. Notwithstanding this regulatory argument, the small potential Rn inventory means that the formation and transport of Rn gas can also be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.2 Speciation

SCR-6.5.2.1 FEP Number: W56
FEP Title: *Speciation*

SCR-6.5.2.1.1 Screening Decision: UP – Disposal Room
UP – Culebra
SO-C – Beneficial – Shaft Seals

Chemical *Speciation* is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms and the degree of chemical retardation estimated during contaminant transport. The effects of cementitious seals on chemical *Speciation* have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.2.1.2 Summary of New Information

Actinide solubilities have been recalculated for the CRA-2014 (Brush and Domski 2013a; Brush and Domski 2013b; and Brush and Domski 2013c) based on the latest inventory components as provided in Van Soest (Van Soest 2012). These new solubilities do not affect the screening arguments or decisions below.

SCR-6.5.2.1.3 Screening Argument

Chemical speciation refers to the form in which elements occur under a particular set of chemical or environmental conditions. Conditions affecting chemical speciation include the temperature, pressure, and salinity (ionic strength) of the water in question. The importance of chemical speciation lies in its control of the geochemical reactions likely to occur and the consequences for actinide mobility.

SCR-6.5.2.1.3.1 Disposal Room

The concentrations of radionuclides that dissolve in any brines present in the disposal rooms after repository closure will depend on the stability of the chemical species that form under the prevailing conditions (for example, temperature, pressure, and ionic strength). The method used to derive radionuclide solubilities in the disposal rooms (see Brush and Domski 2013a) considers the expected conditions. The MgO backfill will buffer pH values in the disposal room to between 9 and 10. Thus, chemical *Speciation* is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms.

SCR-6.5.2.1.3.2 Repository (Shaft) Seals

Certain repository materials, including the cementitious components of the shaft seals, have the potential to interact with groundwater and significantly alter the chemical speciation of any radionuclides present. In particular, extensive use of cementitious materials in the seals may have the capacity to buffer groundwater to extremely high pH (for example, Bennett et al. 1992, pp. 315–25). At high pH values, the speciation and adsorption behavior of many radionuclides is such that their dissolved concentrations are reduced in comparison with near-neutral waters. This effect reduces the migration of radionuclides in dissolved form. The effects of cementitious seals on groundwater chemistry have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.2.1.3.3 Culebra

Chemical speciation will affect actinide retardation in the Culebra. The dependence of An retardation on speciation in the Culebra is accounted for in PA calculations by sampling over ranges of K_ds. The ranges of K_ds are based on the range of groundwater compositions and speciation in the Culebra, including consideration of nonradionuclide solutes. The methodology used to simulate sorption in the Culebra is described in Appendix PA-2014, Section PA-4.9.

SCR-6.5.2.2 FEP Number: W57
FEP Title: *Kinetics of Speciation*

SCR-6.5.2.2.1 Screening Decision: SO-C

The effects of reaction kinetics in chemical speciation reactions have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.2.2.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.5.2.2.3 Screening Argument

Chemical speciation of actinides describes the composition and relative distribution of dissolved species, such as the hydrated metal ion, or complexes, whether with organic or inorganic ligands. Conditions affecting chemical speciation include temperature, ionic strength, ligand concentration, and pH of the solution. Some ligands, such as hydroxide, may act to decrease An solubility, while others, such as citrate, frequently have the opposite influence, often increasing An solubility.

SCR-6.5.2.2.4 Disposal Room Equilibrium Conditions

The concentrations of radionuclides that can be dissolved in brines within the disposal rooms will depend on the thermodynamic stabilities and solubilities of the respective metal complexes. Geochemical modeling using the code EQ3/6 to determine the brine solubilities of radionuclides takes into account the expected conditions, including temperature, ionic strength, pH, and ligand concentration. The chemical speciation at equilibrium is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms.

SCR-6.5.2.2.5 Kinetics of Complex Formation

The waste that is emplaced within the WIPP contains radionuclides, including actinides or An-bearing materials in solid phases, e.g., metal oxides, salts, coprecipitated solids, and contaminated objects. In the event of contact with brine, the solution phase concentration of dissolved radionuclides is controlled both by the solution composition and by the kinetics of dissolution of the solid phases, effectively approaching equilibrium from undersaturation. Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonate and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and ethylene diamine tetra-acetate (EDTA) are kinetically very fast, reaching equilibrium in fractions of a second, an inconsequentially short time increment on the scale of the 10,000-yr regulatory period. Reactions of these types are generally so fast that special techniques must be adopted to measure the reaction rates; as a practical matter, the reaction rate is limited by the mixing rate when metal solutions are combined with ligand solutions. As a result, the rate of approach to an equilibrium distribution of solution species takes place much more rapidly than dissolution, making the dissolution reaction the rate-limiting step. The effects of reaction kinetics in aqueous systems are discussed by Lasaga et al. (Lasaga et al. 1994), who suggest that in contrast to many heterogeneous reactions, homogeneous aqueous geochemical speciation reactions involving relatively small inorganic species occur rapidly and are accurately described by thermodynamic equilibrium models that neglect explicit consideration of reaction kinetics.

For that reason, the rate at which solution species approach equilibrium distribution is of no consequence to repository performance. Kinetics of chemical speciation may be eliminated from PA calculations on the basis of no consequence.

SCR-6.5.3 Precipitation and Dissolution

SCR-6.5.3.1 FEP Numbers: W58, W59, and W60

FEP Titles: *Dissolution of Waste* (W58)
Precipitation of Secondary Minerals (W59)
Kinetics of Precipitation and Dissolution (W60)

SCR-6.5.3.1.1 Screening Decision: UP – W58

SO-C Beneficial – W59
SO-C – W60

Waste dissolution and the release of radionuclides in the disposal rooms are accounted for in PA calculations. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The effect of reaction kinetics in controlling the rate of waste dissolution within the disposal rooms has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.3.1.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.5.3.1.3 Screening Argument

Dissolution of waste and precipitation of secondary minerals control the concentrations of radionuclides in brines and can influence rates of contaminant transport. Waste dissolution is accounted for in PA calculations. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. Results of actinide studies that in some in some cases identify phase formation are provided in Appendix SOTERM-2014, Section 3.0. These results do not affect the screening arguments or decisions.

At low temperatures, precipitation and dissolution reactions are caused by changes in fluid chemistry that result in chemical undersaturation or oversaturation (Bruno and Sandino 1987). Precipitation can be divided into two stages: nucleation and crystal growth. Following nucleation, growth rates depend on the rates of surface processes and the transport of materials to the growth site. Mineral dissolution often depends on whether a surface reaction or transport of material away from the reaction site acts as the rate-controlling process. The former case may cause selective dissolution along crystallographically controlled features, whereas the latter may induce rapid bulk dissolution (Berner 1981). Thus, a range of kinetic behaviors will be exhibited by different mineral precipitation and dissolution reactions in geochemical systems.

SCR-6.5.3.1.3.1 Disposal Room

The waste that is emplaced within the WIPP contains radionuclides, including actinides or An-bearing materials in solid phases, e.g., metal oxides, salts, coprecipitated solids, and contaminated objects. In the event of contact with brine, the solution phase concentration of dissolved radionuclides is controlled both by the solution composition and the kinetics of dissolution of the solid phases, effectively approaching equilibrium from undersaturation. Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonated and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and EDTA are kinetically very fast, reaching equilibrium in less than 1 s, which is infinitesimally small on the time scale of the 10,000-yr regulatory period. The rate at which thermodynamic equilibrium is approached between solution composition and the solubility-controlling solid phases will be limited by rate of dissolution of the solid materials in the waste. As a result, until equilibrium is reached, the solution concentration of the actinides will be lower than the concentration predicted based upon equilibrium of the solution phase components with the solubility-limiting solid phases. The WIPP An source term model, which describes interactions of the waste and brine, is described in detail in the CCA, Chapter 6.0, Section 6.4.3.5. The assumption of instantaneous equilibrium in waste dissolution reactions is a conservative approach, yielding maximum concentration estimates for radionuclides in the disposal rooms because a time-weighted average resulting from a kinetically accurate estimate of solution compositions would have lower concentrations at early times. Waste dissolution at the thermodynamic equilibrium solubility limit is accounted for in PA calculations. However, the kinetics of dissolution within the disposal rooms has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.3.1.3.2 Geological Units

During groundwater flow, radionuclide precipitation processes that occur will lead to reduced contaminant transport. No credit is given in PA calculations to the potentially beneficial occurrence of precipitation of secondary minerals. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to disposal system performance. As a result, kinetics of precipitation has also been eliminated from PA calculations because no credit is taken for precipitation reactions.

SCR-6.5.4 Sorption

SCR-6.5.4.1 FEP Numbers: W61, W62, and W63

FEP Titles: *Actinide Sorption* (W61)
Kinetics of Sorption (W62)
Changes in Sorptive Surfaces (W63)

SCR-6.5.4.1.1 Screening Decision: UP – (W61, W62) In the Culebra and Dewey Lake

SO-C – Beneficial – (W61, W62) In the Disposal Room, Shaft Seals, Panel Closures, Other Geologic Units
UP – (W63)

Sorption within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of sorption processes in shaft seals and panel closures have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. Sorption within the Culebra and the Dewey Lake is accounted for in PA calculations. Sorption processes within other geological units of the disposal system have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. Mobile adsorbents (for example, microbes and humic acids), and the sorption of radionuclides at their surfaces, are accounted for in PA calculations in the estimates of the concentrations of actinides that may be carried. The potential effects of reaction kinetics in adsorption processes and of *Changes in Sorptive Surfaces* are accounted for in PA calculations.

SCR-6.5.4.1.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.5.4.1.3 Screening Argument

Sorption may be defined as the accumulation of matter at the interface between a solid and an aqueous solution. Within PA calculations, including those made for the WIPP, the use of isotherm representations of An sorption prevails because of their computational simplicity in comparison with other models (Serne 1992, pp. 238−39). New mineral colloid and biosorption data for colloid formation have been used to update colloidal enhancement factors (see Appendix SOTERM-2014, Section SOTERM 3.9). This new information does not change the screening arguments, decisions, or implementation of these FEPs within PA.

The mechanisms that control the kinetics of sorption processes are, in general, poorly understood. Often, sorption of inorganic ions on mineral surfaces is a two-step process consisting of a short period (typically minutes) of diffusion-controlled, rapid uptake, followed by slower processes (typically weeks to months) including surface rearrangement, aggregation and precipitation, and solid solution formation (Davis and Kent 1990, p. 202). Available data concerning rates of sorption reactions involving the important radionuclides indicate that, in general, a range of kinetic behavior is to be expected.

The relevance to the WIPP of sorption reaction kinetics lies in their effects on chemical transport. Sorption of waste contaminants to static surfaces of the disposal system, such as seals and host rocks, acts to retard chemical transport. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (nonequilibrium).

The following subsections discuss sorption in the disposal rooms, shaft seals, panel closures, the Culebra, and other geological units of the WIPP disposal system. Sorption on colloids, microbes, and particulate material is also discussed.

SCR-6.5.4.1.3.1 Disposal Room

The concentrations of radionuclides that dissolve in waters entering the disposal room will be controlled by a combination of sorption and dissolution reactions. However, because sorption processes are surface phenomena, the amount of material likely to be involved in sorption mass transfer processes will be small relative to that involved in the bulk dissolution of waste. The WIPP PA calculations therefore assume that dissolution reactions control radionuclide concentrations. Sorption on waste, containers, and backfill within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4 Shaft Seals and Panel Closures

The CCA, Chapter 3.0 and Appendix SEAL describe the seals that are to be placed at various locations in the access shafts and waste panel access tunnels. The materials to be used include crushed salt, bentonite clay, and cementitious grouts. Of these, the latter two in particular possess significant sorption capacities. No credit is given for the influence of sorption processes that may occur in seal materials and their likely beneficial effects on radionuclide migration rates. The effects of sorption processes in shaft seals and panel closures have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4.1 Culebra

Sorption within the Culebra is accounted for in PA calculations as discussed in the CCA, Chapter 6.0, Section 6.4.6.2. The model used comprises an equilibrium, sorption isotherm approximation, employing constructed CDFs of K_ds applicable to dolomite in the Culebra. The potential effects of reaction kinetics in adsorption processes are encompassed in the ranges of K_ds used. The geochemical speciation of the Culebra groundwaters and the effects of changes in sorptive surfaces are implicitly accounted for in PA calculations for the WIPP in the ranges of K_ds used.

SCR-6.5.4.1.4.2 Other Geological Units

During groundwater flow, any radionuclide sorption processes that occur between dissolved or colloidal actinides and rock surfaces will lead to reduced rates of contaminant transport. The sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter it from being released to the accessible environment over 10,000 yrs (Wallace et al. 1995). Thus, sorption within the Dewey Lake is accounted for in PA calculations, as discussed in the CCA, Chapter 6.0, Section 6.4.6.6. No credit is given to the potentially beneficial occurrence of sorption in other geological units outside the Culebra. Sorption processes within other geological units of the disposal system have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4.3 Sorption on Colloids, Microbes, and Particulate Material

The interactions of sorption processes with colloidal, microbial, or particulate transport are complex. Neglecting sorption of contaminants on immobile surfaces in the repository shafts and Salado (for example, the clays of the Salado interbeds) is a conservative approach because it leads to overestimated transport rates. However, neglecting sorption on potentially mobile adsorbents (for example, microbes and humic acids) cannot be shown to be conservative with respect to potential releases, because mobile adsorbents may act to transport radionuclides sorbed to them. Consequently, the concentrations of actinides that may be carried by mobile adsorbents are accounted for in PA calculations (see the CCA, Chapter 6.0, Section 6.4.3.6).

SCR-6.5.5 Reduction-Oxidation Chemistry

SCR-6.5.5.1	**FEP Numbers:**	W64 and W66
	FEP Titles:	*Effects of Metal Corrosion* *Reduction-Oxidation Kinetics*

SCR-6.5.5.1.1 Screening Decision: UP

The effects of reduction-oxidation reactions related to metal corrosion on reduction-oxidation conditions are accounted for in PA calculations. Reduction-oxidation reaction kinetics are accounted for in PA calculations.

SCR-6.5.5.1.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.5.5.1.3 Screening Argument

SCR-6.5.5.1.3.1 Reduction-Oxidation Kinetics

In general, investigation of the reduction-oxidation couples present in aqueous geochemical systems suggests that most reduction-oxidation reactions are not in thermodynamic equilibrium (Wolery 1992, p. 27). The lack of data characterizing the rates of reactions among trace element reduction-oxidation couples leads to uncertainty in elemental speciation. This uncertainty in reduction-oxidation kinetics is accounted for in PA calculations in the dissolved An source term model (see Appendix SOTERM-2014, Section SOTERM-4.3), which estimates the probabilities that particular actinides occur in certain oxidation states. New data regarding reduction of plutonium by iron in WIPP brine are summarized in Appendix SOTERM-2014, Section 3.6.2. This new information does not affect the screening argument or decision for these FEPs.

SCR-6.5.5.1.3.2 Corrosion

Other than gas generation, which is discussed in FEPs W44 through W55, the main effect of metal corrosion will be to influence the chemical conditions that prevail within the repository. Ferrous metals will be the most abundant metals in the WIPP, and these will corrode on contact with any brines entering the repository. Initially, corrosion will occur under oxic conditions owing to the atmospheric oxygen present in the repository at the time of closure. However, consumption of the available oxygen by corrosion reactions will rapidly lead to anoxic (reducing) conditions. These changes and controls on conditions within the repository will affect the chemical speciation of the brines and may affect the oxidation states of the actinides present. Changes to the oxidation states of the actinides will lead to changes in the concentrations that may be mobilized during brine flow. The oxidation states of the actinides are accounted for in PA calculations by the use of parameters that describe probabilities that the actinides exist in particular oxidation states and, as a result, the likely An concentrations. Therefore, the effects of metal corrosion are accounted for in PA calculations.

SCR-6.5.5.2 FEP Number: W65
FEP Title: *Reduction-Oxidation Fronts*

SCR-6.5.5.2.1 Screening Decision: SO-P

The migration of *Reduction-Oxidation Fronts* through the repository has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.5.5.2.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.5.5.2.3 Screening Argument

The development of reduction-oxidation fronts in the disposal system may affect the chemistry and migration of radionuclides. Reduction-oxidation fronts separate regions that may be characterized, in broad terms, as having different oxidation potentials. On either side of a reduction-oxidation front, the behavior of reduction-oxidation-sensitive elements may be controlled by different geochemical reactions. Elements that exhibit the greatest range of oxidation states (for example, U, Np, and Pu) will be the most affected by reduction-oxidation front development and migration. The migration of reduction-oxidation fronts may occur as a result of diffusion processes, or in response to groundwater flow, but will be restricted by the occurrence of heterogeneous buffering reactions (for example, mineral dissolution and precipitation reactions). Indeed, these buffering reactions cause the typically sharp, distinct nature of reduction-oxidation fronts.

Of greater significance is the possibility that the flow of fluids having different oxidation potentials from those established within the repository might lead to the development and migration of a large-scale reduction-oxidation front. Reduction-oxidation fronts have been observed in natural systems to be the loci for both the mobilization and concentration of radionuclides, such as U. For example, during investigations at two U deposits at Poços de Caldas, Brazil, U was observed by Waber (Waber 1991) to be concentrated along reduction-oxidation fronts at the onset of reducing conditions by its precipitation as U oxide. In contrast, studies of the Alligator Rivers U deposit in Australia by Snelling (Snelling 1992) indicated that the movement of the relatively oxidized weathered zone downwards through the primary ore body as the deposit was eroded and gradually exhumed led to the formation of secondary uranyl-silicate minerals and the mobilization of U in its more soluble U(VI) form in near-surface waters. The geochemical evidence from these sites suggests that the reduction-oxidation fronts had migrated only slowly, at most on the order of a few tens of meters per million yrs. These rates of migration were controlled by a range of factors, including the rates of erosion, infiltration of oxidizing waters, geochemical reactions, and diffusion processes.

The migration of large-scale reduction-oxidation front through the repository as a result of regional fluid flow is considered unlikely over the regulatory period on the basis of comparison with the slow rates of reduction-oxidation front migration suggested by natural system studies. This comparison is considered conservative because the relatively impermeable nature of the Salado suggests that reduction-oxidation front migration rates at the WIPP are likely to be slower than those observed in the more permeable lithologies of the natural systems studied. Large-scale reduction-oxidation fronts have therefore been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.5.5.3 **FEP Number:** W67
FEP Title: *Localized Reducing Zones*

SCR-6.5.5.3.1 Screening Decision: SO-C

The formation of *Localized Reducing Zones* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.5.3.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.5.5.3.3 Screening Argument

The dominant reduction reactions in the repository include steel corrosion and microbial degradation. The following bounding calculation shows that molecular diffusion alone will be sufficient to mix brine chemistry over a distance of meters and therefore the formation of localized reducing zones in the repository is of low consequence.

The diffusion of a chemical species in a porous medium can be described by Fick's equation (e.g., Richardson and McSween 1989, p.132):

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial X}\left(D_{eff}\,\frac{\partial C}{\partial X}\right) \qquad \text{(SCR.17)}$$

where C is the concentration of the diffusing chemical species, t is the time, X is the distance, and D_{eff} is the effective diffusivity of the chemical species in a given porous medium. D_{eff} is related to the porosity (ϕ) of the medium by (e.g., Oelkers 1996):

$$D_{eff} = \phi^2 D \qquad \text{(SCR.18)}$$

where D is the diffusivity of the species in pure solution. The D values for most aqueous species at room temperatures fall into a narrow range, and 10^{-5} cm^2 (1.5×10^{-6} in.^{2}) per s is a good approximation (e.g., Richardson and McSween 1989, p.138). From the WIPP PA calculations (Bean et al. 1996, p.7-29; WIPP Performance Assessment 1993, Equation B-8), the porosity in the WIPP waste panels after room closure is calculated to be 0.4 to 0.7. From Equation (SCR.19), the effective diffusivity D_{eff} in the waste is estimated to be $2 - 5 \times 10^{-6}$ cm^2 (7×10^{-7} in.^{2}) per second (= $6 - 16 \times 10^{-3}$ m^2/yr).

Given a time scale of T, the typical diffusion penetration distance (L) can be determined by scaling:

$$L = \sqrt{D_{eff}T} \qquad \text{(SCR.19)}$$

Using Equation (SCR.20), the diffusion penetration distance in the WIPP can be calculated as a function of diffusion time, as shown in Figure SCR-1.

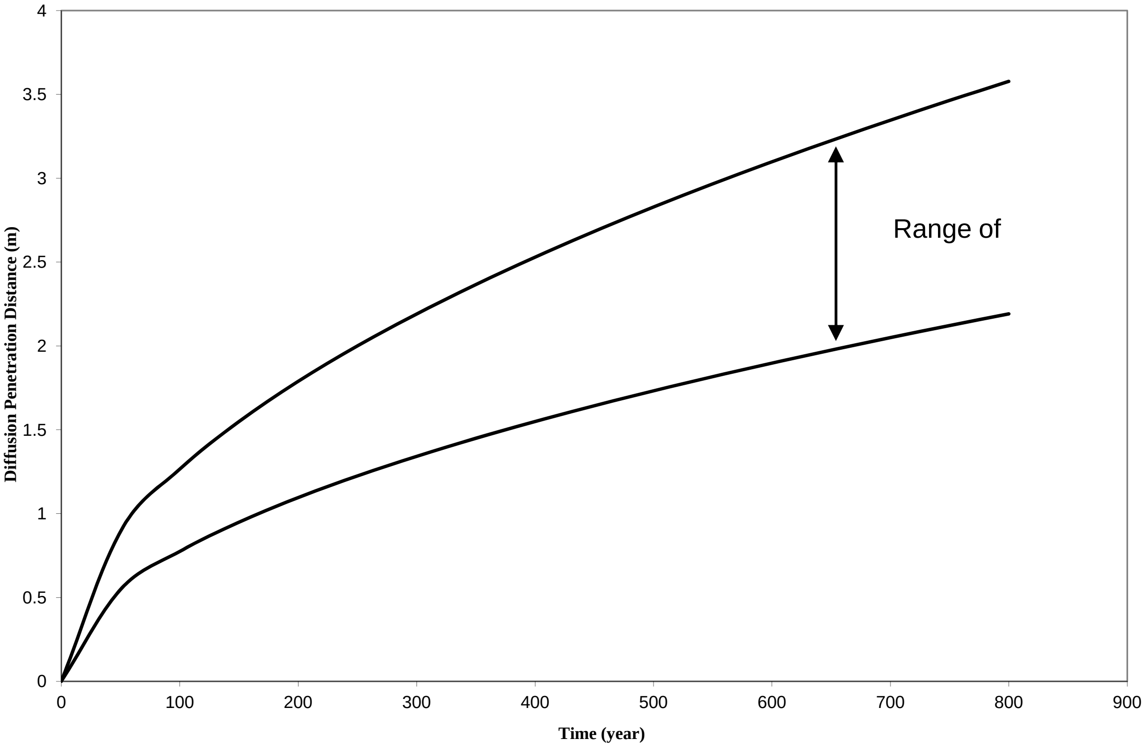

Figure SCR-1. Diffusion Penetration Distance in the WIPP as a Function of Diffusion Time

Direct brine release requires the repository gas pressure to be at least 8 MPa (Stoelzel et al. 1996). The CRA-2014 calculations show that it will take at least 1000 yrs for the repository pressure to reach this critical value by gas generation processes (see Camphouse 2013b, Figure 6-3). Over this time scale, according to Equation (SCR.20) and Figure SCR-1, molecular diffusion alone can mix brine composition effectively at least over a distance of ~ 1 m (3.3 ft).

The above calculation assumes diffusion only through liquid water. This assumption is applicable to steel corrosion, the humid rate of which is zero. Note that microbial reactions can also consume or release gaseous species. The diffusion of a gaseous species is much faster than an aqueous one. Thus, molecular diffusion can homogenize microbial reactions even at a much larger scale.

The height of waste stacks in the repository after room closure (*h*) can be calculated by:

$$h = \frac{h_0\left(1-\varphi_0\right)}{1-\varphi} \qquad \text{(SCR.20)}$$

where h_0 and ϕ_0 are the initial height of waste stacks and the initial porosity of wastes, which are assumed to be 3.96 m and 0.848, respectively, in the WIPP PA. For $\phi = 0.4 – 0.7$, *h* is estimated to be 1.0 to 2.0 m. This means that molecular diffusion alone can homogenize redox reaction in the vertical dimension of the repository. Therefore, the formation of localized reducing zones is unlikely. The general repository environment will become reducing shortly after room closure because of metal corrosion and microbial reactions. Therefore, localized reducing zone*s* can be eliminated from PA calculations on the basis of low consequence to the disposal system.

SCR-6.5.6 Organic Complexation

SCR-6.5.6.11 FEP Numbers: W68, W69, and W71

FEP Titles: *Organic Complexation* (W68)
Organic Ligands (W69)
Kinetics of Organic Complexation (W71)

SCR-6.5.6.1.1 Screening Decision: UP – W68 and W69

SO-C – W71

The effects of anthropogenic *Organic Complexation* reactions, including the effects of *Organic Ligands*, humic, and fulvic acids, have been incorporated in the PA calculations. The kinetics of organic ligand complexation is screened out because the rate at which organic ligands are complexed to actinide is so fast that it has no consequence to repository performance.

SCR-6.5.6.1.2 Summary of New Information

These FEPs have been updated with references to the newest waste inventory (Van Soest 2012) and the most recent solubility calculations (Brush and Domski 2013a). The CRA-2014 PA includes improved treatment of the amount of brine within the repository such that it more accurately represents dissolved radionuclide concentrations over a range of possible brine volumes (see Camphouse 2013a). This change in the implementation of brine volume is considered a model enhancement as it corrects a mass balance issue that was present in previous PAs. FEPs related to this improvement (W68 and W69) continue to be screened in as UP.

SCR-6.5.6.1.3 Screening Argument

From a PA standpoint, the most important actinides are Th, U, Np, Pu, and Am. Dissolved Th, U, Np, Pu, and Am will essentially speciate entirely as Th(IV), U(IV) or U(VI), Np(IV) or Np(V), Pu(III) or Pu(IV), and Am(III) under the strongly reducing conditions expected as a result of the presence of Fe(II) and microbes (see Appendix SOTERM-2014, Section SOTERM-4.3). New WIPP-specific data on the effects of organic complexation on neodymium and thorium are summarized in Appendix SOTERM-2014, Section 3.8.2. This new information does not affect the screening argument or decision for these FEPs.

Some organic ligands can increase the actinide solubilities. An estimate of masses of the complexing agents in the TRU solidified waste forms scheduled for disposal in the WIPP is presented in Van Soest (Van Soest 2012). Acetate, citrate, oxalate, and EDTA were determined to be the only water-soluble and actinide-complexing organic ligands present in significant quantities in the inventory. These ligands and their complexation with actinides (Th(IV), U(VI), Np(V), and Am(III)) in a variety of ionic strength media were studied at Florida State University (FSU) (Choppin et al. 2001). The FSU studies showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved An concentrations. Lactate behavior was also studied at FSU because it appeared in the preliminary inventory of nonradioactive constituents of the TRU waste to be emplaced in the WIPP (Brush 1990); lactate did not appear in the current inventory (Van Soest 2012).

Although the FSU experimental work on organic ligands complexation showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved An concentrations, SNL did not include the results in the FMT calculations for the CCA PA because (1) the thermodynamic database for organic complexation of actinides was not considered adequate at the time, and (2) side-calculations using thermodynamic data for low-ionic-strength NaCl solutions showed that transition metals (in particular iron, nickel, chromium, vanadium, and manganese present in waste drum steel) would compete effectively with the actinides for the binding sites on the organic ligands, thus preventing significant complexation of actinides.

The solubilities of the actinides are calculated using EQ3/6, a software package for calculating actinide concentration limits based on thermodynamic parameters. The parameters for EQ3/6 are derived both from experimental investigations specifically designed to provide parameter values for this model and from the published literature. The CRA-2014 calculations include the effects of organic ligands (acetate, citrate, EDTA, and oxalate) on actinide solubilities in the EQ3/6 calculations (Brush and Domski 2013b). The EQ3/6 database includes all of the results of experimental studies (Choppin et al. 2001) required to predict the complexation of dissolved An(III), An(IV), and An(V) species by acetate, citrate, EDTA, and oxalate (Giambalvo 2002a and Giambalvo 2002b).

Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonate and hydroxide, and with organic ligands, such as acetate, citrate, oxalate, and EDTA, are kinetically very fast, reaching equilibrium in fractions of a second, an inconsequentially short time increment on the scale of the 10,000-yr regulatory period. Reactions of these types are generally so fast that special techniques must be adopted to measure the reaction rates; as a practical matter, the reaction rate is limited by the mixing rate when metal solutions are combined with ligand solutions.

For that reason, the rate at which organic ligands are complexed to actinide is of no consequence to repository performance. Kinetics of organic complexation may be eliminated from PA calculations on the basis of no consequence.

Organic ligands can also influence potential retardation of radionuclides in geologic materials. Organic ligand concentration in repository brine could reduce K_ds in the Culebra. The impact of organic ligands on K_d ranges used in radionuclide transport calculations was included in PA for the CRA-2009 PABC (Kuhlman 2010). The CRA-2014 uses these revised ranges.

SCR-6.5.6.2 **FEP Number:** W70
FEP Title: *Humic and Fulvic Acids*

SCR-6.5.6.2.1 Screening Decision: UP

The presence of *Humic Acids* and *Fulvic Acids* is incorporated in PA calculations.

SCR-6.5.6.2.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.5.6.2.3 Screening Argument

The occurrence of humic acids and fulvic acids is incorporated in PA calculations in the models for radionuclide transport by humic colloids (see Appendix PA-2014, Section PA-4.3).

SCR-6.5.7 Chemical Effects on Material Properties

SCR-6.5.7.1

FEP Numbers: W74, W76, and W115
FEP Titles: *Chemical Degradation of Shaft Seals* (W74)
Microbial Growth on Concrete (W76)
Chemical Degradation of Panel Closures (W115)

SCR-6.5.7.1.1 Screening Decision: UP (W74 and W76)

SO-P (W115)

The effects of *Chemical Degradation of Shaft Seals*, and *Microbial Growth on Concrete* are accounted for in PA calculations. *Chemical Degradation of Panel Closures* has been screened out based on low probability.

SCR-6.5.7.1.2 Summary of New Information

The CRA-2014 PA represents a new panel closure system constructed of run-of-mine (ROM) salt. Historically, FEP W115 *Chemical Degradation of Panel Closures* has been included in past PA calculations (classified UP), due to the potential for concrete to degrade in the repository environment. However, because the new PCS will be constructed of ROM salt, it is no longer appropriate to include in PA calculations because, unlike the concrete in the Option D panel closure, the ROM salt will not be susceptible to chemical degradation. The ROM salt closure will be identical to the host rock chemistry, which will be at chemical equilibrium with any brine from the near field. In the event brine were present that differed significantly from the host rock chemistry, the PCS material will not be preferentially degraded from that of the host rock.

SCR-6.5.7.1.3 Screening Argument

The concrete used in the shaft seal systems will degrade as a result of chemical reaction with the infiltrating groundwater. Degradation could lead to an increase in permeability of the seal system. The main uncertainties with regard to cement degradation rates at the WIPP are the effects of groundwater chemistry, the exact nature of the cementitious phases present, and the rates of brine infiltration. The PA calculations take a conservative approach to these uncertainties by assuming a large increase in permeability of the concrete seals only a few hundred yrs after closure. These permeability values are based on seal design considerations and consider the potential effects of degradation processes. Therefore, the effects of chemical degradation of shaft seals are accounted for in PA calculations through the CDFs used for seal material permeabilities. The panel closures are planned to be constructed of ROM salt. Due to the salt construction, chemical degradation is not expected to occur to the ROM salt PCS.

Concrete can be inhabited by alkalophilic bacteria, which could produce acids, thereby accelerating the seal degradation process. Nitrification processes, which will produce nitric acid, tend to be aerobic, and will be further limited at the WIPP by the low availability of ammonium in the brines (Pedersen and Karlsson 1995, p. 75). Because of the limitations on growth caused by the chemical conditions, it is likely that the effects of microbial growth on concrete will be small. The effects of such microbial activity on seal properties are, therefore, implicitly accounted for in PA calculations through the CDFs used for seal material permeabilities.

SCR-6.5.7.2 **FEP Number:** W75
FEP Title: *Chemical Degradation of Backfill*

SCR-6.5.7.2.1 Screening Decision: SO-C

The effects on material properties of the *Chemical Degradation of Backfill* have been eliminated from PA calculations on the basis of low consequence.

SCR-6.5.7.2.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.5.7.2.3 Screening Argument

Degradation of the chemical conditioners or backfill added to the disposal room is a prerequisite of their function in buffering the chemical environment of the disposal room. However, the chemical reactions (Snider 2001) and dissolution involved will change the physical properties of the material. Because the mechanical and hydraulic characteristics of the backfill have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system, the effects of the chemical degradation of backfill on material properties have been eliminated from PA calculations on the same basis.

SCR-6.6 Contaminant Transport Mode FEPs

SCR-6.6.1 Solute and Colloid Transport

SCR-6.6.1.1 **FEP Number:** W77
FEP Title: *Solute Transport*

SCR-6.6.1.1.1 Screening Decision: UP

Transport of dissolved radionuclides is accounted for in PA calculations.

SCR-6.6.1.1.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.6.1.1.3 Screening Argument

Solute transport may occur by advection, dispersion, and diffusion down chemical potential gradients, and is accounted for in PA calculations (see Appendix PA-2014, Section PA-4.3).

SCR-6.6.1.2

FEP Numbers: W78, W79, W80, and W81
FEP Titles: *Colloidal Transport* (W78)
Colloidal Formation and Stability (W79)
Colloidal Filtration (W80)
Colloidal Sorption (W81)

SCR-6.6.1.2.1 Screening Decision: UP

Formation of colloids, transport of colloidal radionuclides, and colloid retardation through filtration and sorption are accounted for in PA calculations.

SCR-6.6.1.2.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.6.1.2.3 Screening Argument

Colloids typically have sizes of between 1 nm and 1 μm and may form stable dispersions in groundwaters. Colloid formation and stability depends on their composition and the prevailing chemical conditions (for example, salinity). Depending on their size, colloid transport may occur at different rates than those of fully dissolved species. They may be physically excluded from fine porous media, and their migration may be accelerated through fractured media in channels where velocities are greatest. However, they can also interact with the host rocks during transport and become retarded. These interactions may be of a chemical or physical nature and include electrostatic effects leading to colloid sorption, and sieving leading to colloid filtration and pore blocking. Colloidal formation and stability is accounted for in PA calculations through estimates of colloid numbers in the disposal room based on the prevailing chemical conditions (Appendix SOTERM-2014, Section SOTERM-4.6). Colloidal sorption, colloidal filtration, and colloidal transport in the Culebra are accounted for in PA calculations (CCA Section 6.4.6.2.2). New WIPP-relevant data regarding colloid formation and transport can be found in Appendix SOTERM-2014, Section 3.9. This information does not affect the screening argument or decision for this FEP.

SCR-6.6.2 Particle Transport

SCR-6.6.2.1 **FEP Numbers:** W82, W83, W84, W85, and W86
FEP Titles: *Suspension of Particles* (W82)
Rinse (W83)
Cuttings (W84)
Cavings (W85)
Spallings (W86)

SCR-6.6.2.1.1 Screening Decision: DP W82, W84, W85, W86
SO-C W83

The formation of particulates through *Rinse* and subsequent transport of radionuclides in groundwater and brine has been eliminated from PA calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system. The transport of radionuclides as particulates (cuttings, cavings, and spallings) during penetration of the repository by a borehole, is accounted for in PA calculations.

SCR-6.6.2.1.2 Summary of New Information

Recent experiments (Herrick et al. 2012) on surrogate waste materials has resulted in new parameter values for the shear strength of waste. This parameter directly affects the amount of cavings (W85) during intrusion scenarios. Additionally, the improved implementation of water balance (Camphouse 2013a) within the repository may indirectly affect spallings (W86). These enhancements are downstream of the screening process and will not affect either of these FEPs; they remain included in disturbed scenarios and are classified DP.

SCR-6.6.2.1.3 Screening Argument

Suspensions of particles that have sizes larger than colloids are unstable because the particles undergo gravitational settling. It is unlikely that brine flow will be rapid enough within the WIPP disposal rooms to generate particulate suspensions through rinse and transport under undisturbed conditions. Mobilization of suspensions would effect a local and minor redistribution of radionuclides within the room and would not result in increased radionuclide transport from the repository. The formation of particulates through rinse and transport of radionuclides in groundwater and brine has been eliminated from PA calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system.

Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (FEPs H21 and H23, Section SCR-5.2.1.1 and Section SCR-5.2.1.3). This waste could include material intersected by the drill bit (cuttings), material eroded from the borehole wall by circulating drilling fluid (cavings), and material that enters the borehole as the repository depressurizes (spallings). Transport of radionuclides by these materials and in brine is accounted for in PA calculations and is discussed in Appendix PA-2014, Sections PA-4.5 and PA-4.6.

SCR-6.6.3 Microbial Transport

SCR-6.6.3.1 **FEP Number:** W87
FEP Title: *Microbial Transport*

SCR-6.6.3.1.1 Screening Decision: UP

Transport of radionuclides bound to microbes is accounted for in PA calculations.

SCR-6.6.3.1.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.6.3.1.3 Screening Argument

Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system. Because of their colloidal size, microbes, and any radionuclides bound to them, may be transported at different rates than radionuclides in solution. Microbial transport of radionuclides is accounted for in PA calculations (Appendix SOTERM-2014, Section SOTERM-3.9.2.3 and Reed et al. (Reed et al. 2013). New data on the formation of biocolloids is summarized in Appendix SOTERM-2014, Section 3.9.2.3 and Reed et al. (Reed et al. 2013). This information does not affect the screening argument or decision for this FEP.

SCR-6.6.3.2 **FEP Number:** W88
FEP Title: *Biofilms*

SCR-6.6.3.2.1 Screening Decision: SO-C Beneficial

The effects of *Biofilms* on microbial transport have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.6.3.2.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.6.3.2.3 Screening Argument

Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system.

Biofilms may influence microbial and radionuclide transport rates through their capacity to retain, and therefore retard, both the microbes themselves and radionuclides. The formation of biofilms in deep subsurface environments such as in the WIPP is controversial. Since the microbial degradation experiments at Brookhaven National Laboratory bracket expected repository conditions, the potential effect of biofilms formation on microbial degradation and transport, if any, has been captured in the PA parameters derived from those experiments (Francis and Gillow 1994; Francis et al. 1997; Francis and Gillow 2000; Gillow and Francis 2001a and Gillow and Francis 2001b; Gillow and Francis 2002a and Gillow and Francis 2002b). As a matter of fact, no apparent formation of stable biofilms was observed in the Brookhaven National Laboratory experiments. The formation of biofilms tends to reduce cell suspension and mobility. Additional information on the microbial ecology of WIPP is provided in Appendix SOTERM-2014, Section 2.4.1. This effect has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.6.4 Gas Transport

SCR-6.6.4.1 **FEP Number:** W89
FEP Title: *Transport of Radioactive Gases*

SCR-6.6.4.1.1 Screening Decision: SO-C

The *Transport of Radioactive Gases* has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.6.4.1.2 Summary of New Information

This FEP discussion has been updated to include recent inventory information. This new information does not affect the screening argument or decision for this FEP.

SCR-6.6.4.1.3 Screening Argument

The production and potential transport of radioactive gases are eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Transportable radioactive gases are comprised mainly of isotopes of Rn and ^{14}C. Rn gases are eliminated from PA because their inventory is small (<4 Ci) (Van Soest 2012), and their half-lives are short (<4 days), resulting in insignificant potential for release from the repository.

SCR-6.7 Contaminant Transport Processes

SCR-6.7.1 Advection

SCR-6.7.1.1 **FEP Number:** W90
FEP Title: *Advection*

SCR-6.7.1.1.1 Screening Decision: UP

Advection of contaminants is accounted for in PA calculations.

SCR-6.7.1.1.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.7.1.1.3 Screening Argument

Advection (that is, the transport of dissolved and solid material by flowing fluid) is accounted for in PA calculations (Appendix PA-2014, Section PA-4.3).

SCR-6.7.2 Diffusion

SCR-6.7.2.1

FEP Numbers: W91 and W92
FEP Titles: *Diffusion* (W91)
Matrix Diffusion (W92)

SCR-6.7.2.1.1 Screening Decision: UP

Diffusion of contaminants and retardation by *Matrix Diffusion* are accounted for in PA calculations.

SCR-6.7.2.1.2 Summary of New Information

No new information has been identified that affects the screening of this FEP since the CRA-2009.

SCR-6.7.2.1.3 Screening Argument

Diffusion (that is, the movement of molecules or particles both parallel to and transverse to the direction of advection in response to Brownian forces) and, more specifically matrix diffusion, whereby movement is transverse to the direction of advection within a fracture and into the surrounding rock matrix, are accounted for in PA calculations (Appendix PA-2014, Section PA-4.9).

SCR-6.7.3 Thermochemical Transport Phenomena

SCR-6.7.3.1

FEP Number: W93
FEP Title: *Soret Effect*

SCR-6.7.3.1.1 Screening Decision: SO-C

The effects of thermochemical transport phenomena (the *Soret Effect*) have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.3.1.2 Summary of New Information

This FEP has been updated with new thermal heat rise values for Al corrosion and MgO hydration, based on the latest inventory data (Van Soest 2012). These values continue to be low and do not affect the screening argument or decision for this FEP.

SCR-6.7.3.1.3 Screening Argument

According to Fick's law, the diffusion flux of a solute is proportional to the solute concentration gradient. In the presence of a temperature gradient there will also be a solute flux proportional to the temperature gradient (the Soret Effect). Thus, the total solute flux, *J*, in a liquid phase may be expressed as

$$J = -D\overline{\nabla}C - ND\overline{\nabla}T \tag{SCR.21}$$

where *C* is the solute concentration, *T* is the temperature of the liquid, *D* is the solute diffusion coefficient, and

$$N = S_T C\left(1 - C\right) \tag{SCR.22}$$

in which S_T is the Soret coefficient. The mass conservation equation for solute diffusion in a liquid is then

$$\frac{\partial C}{\partial t} = \nabla \cdot \left(D\nabla C + ND\nabla T\right) \tag{SCR.23}$$

When temperature gradients exist in solutions with both light and heavy solute molecules, the heavier molecules tend to concentrate in the colder regions of the solution. Typically, large temperature gradients are required for Soret diffusion to be significant compared to Fickian diffusion.

Radioactive decay, nuclear criticality, and exothermic reactions are three possible sources of heat in the WIPP repository. The U.S. DOE (U.S. DOE 1980) estimated that radioactive decay of CH-TRU waste will result in a maximum temperature rise at the center of the repository of 1.6 °C (2.9 °F) at 80 yrs after waste emplacement. Sanchez and Trellue (Sanchez and Trellue 1996) have shown that the total thermal load of RH-TRU waste will not significantly affect the average temperature increase in the repository. Temperature increases of about 3 °C (5.4 °F) may occur at the locations of RH-TRU containers with maximum thermal power (60 W). Such temperature increases are likely to be short-lived on the time scale of the 10,000-yr regulatory period because of the rapid decay of heat-producing nuclides in RH-TRU waste, such as ^{137}Cs (cesium), ^{90}Sr (strontium), ^{241}Pu, and ^{147}Pm (promethium), whose half-lives are approximately 30, 29, 14, and 3 yrs, respectively. Soret diffusion generated by such temperature gradients will be negligible compared to other radionuclide transport mechanisms.

Temperature increases resulting from exothermic reactions are discussed in Section SCR-6.3.4.1. The maximum temperature rise in the disposal panels will be less than 3.9 °C (7.0 °F) as a consequence of MgO hydration. Note that AICs will prevent drilling within the controlled area for 100 yrs after disposal. Heat generation by radioactive decay and concrete seal hydration will have decreased substantially after 100 yrs, and the temperatures in the disposal panels will have decreased nearly to the temperature of the undisturbed host rock.

If the repository were to be inundated following a drilling intrusion, Al corrosion could, at most, result in a short-lived (two yrs) temperature increase of about 3.4 °C (6.1 °F). These calculated maximum heat generation rates resulting from Al corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 3.9 °C (7.0 °F) represents the maximum that could occur as a result of a combination of exothermic reactions occurring simultaneously. Temperature increases of this magnitude will not result in significant Soret diffusion within the disposal system.

The limited magnitude and spatial scale of temperature gradients in the disposal system indicate that Soret diffusion will be insignificant, allowing the effects of thermochemical transport (Soret Effect) to be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.4 Electrochemical Transport Phenomena

SCR-6.7.4.1 **FEP Number:** W94
FEP Title: *Electrochemical Effects*

SCR-6.7.4.1.1 Screening Decision: SO-C

The effects of electrochemical transport phenomena caused by electrochemical reactions have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.4.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.4.1.3 Screening Argument

The variety of waste metals and metal packaging in the repository may allow galvanic cells spanning short distances to be established. The interactions among the metals depend upon their physical characteristics and the chemical conditions in the repository. For example, good physical and electrical contact, which is critical to the establishment of galvanic cells, may be impeded by electrically nonconductive waste materials. Additionally, in order to establish a galvanic cell, it is necessary that the metals have different values for standard reduction potentials. For example, a galvanic cell is not expected to be formed by contact of two segments of metals with identical compositions. As a result, galvanic cells can only be established by contact of dissimilar metals, as might happen because of contact between a waste drum and the contents, or between contents within a waste package. The localized nature of electrochemical transport is restricted to the size scale over which galvanic cells can develop, i.e., on the order of size of waste packages. Since the possible range of transport is restricted by the physical extent of galvanic activity, electrochemical effects cannot act as long-range transport mechanisms for radionuclides and therefore are of no consequence to the performance of the repository.

SCR-6.7.4.2 FEP Number: W95 FEP Title: *Galvanic Coupling* (outside the repository)

SCR-6.7.4.2.1 Screening Decision: SO-P

The effects of *Galvanic Coupling* between the waste and metals external to the repository on transport have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.7.4.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.4.2.3 Screening Argument

With regard to the WIPP, galvanic coupling refers to the establishment of galvanic cells between metals in the waste form, canisters, and other metals external to the waste form.

Long-range electric potential gradients may exist in the subsurface as a result of groundwater flow and electrochemical reactions. The development of electric potential gradients may be associated with the weathering of sulfide ore bodies, variations in rock properties at geological contacts, bioelectric activity associated with organic matter, natural corrosion reactions, and temperature gradients in groundwater. With the exception of mineralization potentials associated with metal sulfide ores, the magnitude of electric potentials is usually less than about 100 millivolts (mV) and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976). Metals external to the waste form can include natural metallic ore bodies in the host rock. However, metallic ore bodies and metallic sulfide ores do not exist in the region of the repository (the CCA, Appendix GCR). As a result, galvanic coupling between the waste and metallic materials outside the repository cannot occur. Therefore, galvanic coupling is eliminated from PA calculations on the basis of low probability of occurrence over 10,000 yrs.

SCR-6.7.4.3 FEP Number: W96 FEP Title: *Electrophoresis*

SCR-6.7.4.3.1 Screening Decision: SO-C

The effects of electrochemical transport phenomena caused by *Electrophoresis* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.4.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.4.3.3 Screening Argument

Long range (in terms of distance) electric potential gradients may exist in the subsurface as a result of groundwater flow and electrochemical reactions. The development of potentials may be associated with the weathering of sulfide ore bodies, variations in rock properties at geological contacts, bioelectric activity associated with organic matter, natural corrosion reactions, and temperature gradients in groundwater. With the exception of mineralization potentials associated with metal sulfide ores, the magnitude of such potentials is usually less than about 100 mV and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976, p. 458). Short range potential gradients caused by the corrosion of metals within the waste may be set up over distances that are restricted to the size scale of the waste packages.

A variety of metals will be present within the repository as waste metals and metal packaging, which may allow electrochemical cells to be established over short distances. The types of interactions that will occur depend on the metals involved, their physical characteristics, and the prevailing solution conditions. Electrochemical cells that may be established will be small relative to the size of the repository, limiting the extent to which migration of contaminants by electrophoresis can occur. The electric field gradients will be of small magnitude and confined to regions of electrochemical activity in the area immediately surrounding the waste material. As a result, electrophoretic effects on migration behavior caused by both long and short range potential gradients have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5 Physiochemical Transport Phenomena

SCR-6.7.5.1 **FEP Number:** W97
FEP Title: *Chemical Gradients*

SCR-6.7.5.1.1 Screening Decision: SO-C

The effects of enhanced diffusion across *Chemical Gradients* have been eliminated from PAs on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5.1.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.5.1.3 Screening Argument

Chemical gradients within the disposal system, whether induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants.

Gradients will exist at interfaces between different repository materials and between repository and geological materials. Distinct chemical regimes will be established within concrete seals and adjoining host rocks. Similarly, chemical gradients will exist between the waste and the surrounding rocks of the Salado. Other chemical gradients may exist because of the juxtaposition of relatively dilute groundwaters and brines or between groundwaters with different compositions. Natural gradients currently exist between different groundwaters in the Culebra.

Enhanced diffusion is a possible consequence of chemical gradients that occur at material boundaries. However, the distances over which enhanced diffusion could occur will be small in comparison to the size of the disposal system. Processes that may be induced by chemical gradients at material boundaries include the formation or destabilization of colloids. For example, cementitious materials that will be emplaced in the WIPP as part of the waste and the seals contain colloidal-sized materials, such as calcium-silicate-hydrate gels, and alkaline pore fluids. Chemical gradients will exist between the pore fluids in the cementitious materials and the less alkaline surroundings. Chemical interactions at these interfaces may lead to the generation of colloids of the inorganic, mineral fragment type. Colloidal compositions may include calcium oxide, calcium hydroxide, calcium-aluminum silicates, calcium-silicate-hydrate gels, and silica. Experimental investigations of the stability of inorganic, mineral fragment colloidal dispersions have been carried out as part of the WIPP colloid-facilitated actinide transport program (Papenguth and Behl 1996). More recently, the colloidal enhancement parameters for mineral, intrinsic, and microbial colloids were reassessed for the actinide source term for the CRA-2014 PA (Reed et al. 2013). The most important observations for mineral colloids are: (1) there is no evidence for the formation of significant amounts of magnesium-derived mineral colloid species, and (2) iron oxides can lead to long-term and relatively small plutonium mineral colloids in these brine systems, and the concentrations observed are within the current enhancement parameter values (Reed et al. 2013, Section 4.3). Based on these observations, there are no changes in the mineral colloid enhancement parameters for the actinide source term in the CRA-2014 PA. These new results for mineral colloids do not affect the screening decision for this FEP.

SCR-6.7.5.2 **FEP Number:** W98
FEP Title: *Osmotic Processes*

SCR-6.7.5.2.1 Screening Decision: SO-C

The effects of *Osmotic Processes* have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.7.5.2.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.5.2.3 Screening Argument

Osmotic processes, i.e., diffusion of water through a semipermeable or differentially permeable membrane in response to a concentration gradient, may occur at interfaces between waters of different salinities. Osmotic processes can occur if waters of different salinities and/or compositions exist on either side of a particular lithology such as clay, or a lithological boundary that behaves as a semipermeable membrane. At the WIPP, clay layers within the Salado may act as semipermeable membranes across which osmotic processes may occur.

In the absence of a semipermeable membrane, water will move from the more dilute water into the more saline water. However, the migration of dissolved contaminants across an interface may be restricted depending upon the nature of the membrane. A hydrological gradient across a semipermeable membrane may either enhance or oppose water movement by osmosis depending on the direction and magnitude of the gradient. Dissolved contaminants that cannot pass through a semipermeable membrane may be moved towards the membrane and concentrated along the interface when advection dominates over osmosis and reverse osmosis occurs. Thus, both osmosis and reverse osmosis can restrict the migration of dissolved contaminants and possibly lead to concentration along interfaces between different water bodies. The effects of osmotic processes have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.7.5.3 **FEP Number:** W99
FEP Title: *Alpha Recoil*

SCR-6.7.5.3.1 Screening Decision: SO-C

The effects of *Alpha Recoil* processes on radionuclide transport have been eliminated from PA calculations on the basis of low consequence to performance of the disposal system.

SCR-6.7.5.3.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.5.3.3 Screening Argument

Alpha particles are emitted with sufficiently high energies that daughter nuclides recoil appreciably to conserve system momentum. For example, ^{238}U decays to ^{234}Th with emission of a 4.1 megaelectron volt (MeV) alpha particle. The law of conservation of momentum requires that the daughter nuclide, ^{234}Th, recoils in the opposite direction with an energy of approximately 0.07 MeV. The energy is great enough to break chemical bonds or cause ^{234}Th to move a short distance through a crystal lattice. If the ^{234}Th is close enough to the surface of the crystal, it will be ejected into the surroundings. ^{234}Th decays to ^{234}Pa which decays to ^{234}U with respective half-lives of 24.1 days and 1.17 minutes. The recoil and decay processes can lead to the apparent preferential dissolution or leaching of ^{234}U relative to ^{238}U from crystal structures and amorphous or adsorbed phases. Preferential leaching may be enhanced because of radiation damage to the host phase resulting from earlier radioactive decay events. Consequently, ^{234}U sometimes exhibits enhanced transport behavior relative to ^{238}U.

The influence of alpha recoil processes on radionuclide transport through natural geologic media is dependent on many site-specific factors, such as mineralogy, geometry, and microstructure of the rocks, as well as geometrical constraints on the type of groundwater flow, e.g., porous or fracture flow. Studies of natural radionuclide-bearing groundwater systems often fail to discern a measurable effect of alpha-recoil processes on radionuclide transport above the background uncertainty introduced by the spatial heterogeneity of the geological system. Consequently, the effects of the alpha recoil processes that occur on radionuclide transport are thought to be minor. These effects have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5.4 **FEP Number:** W100
FEP Title: *Enhanced Diffusion*

SCR-6.7.5.4.1 Screening Decision: SO-C

Enhanced diffusion is a possible consequence of chemical gradients that occur at material boundaries. However, the distances over which enhanced diffusion could occur will be small in comparison to the size of the disposal system. Therefore, the effects of *Enhanced Diffusion* across chemical gradients at material boundaries have been eliminated from PAs on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5.4.2 Summary of New Information

No new information that affects the screening of this FEP has been identified since the CRA-2009.

SCR-6.7.5.4.3 Screening Argument

Enhanced diffusion only occurs where there are higher than average chemical gradients. The spatial extent of chemical gradients should be quite limited and as enhanced diffusion occurs, it will tend to reduce the chemical gradient. Thus, the driving force for the enhanced diffusion will be reduced and eventually eliminated as the system approaches steady state or equilibrium conditions. Because of the limited spatial extent of enhanced diffusion, its effect on radionuclide transport should be small.

Processes that may be induced by chemical gradients at material boundaries include the formation or destabilization of colloids. For example, cementitious materials, emplaced in the WIPP as part of the waste and the seals, contain colloidal-sized phases such as calcium-silicate-hydrate gels and alkaline pore fluids. Chemical gradients will exist between the pore fluids in the cementitious materials and the less-alkaline surroundings. Chemical interactions at these interfaces may lead to the generation of colloids of the inorganic, mineral-fragment type. Colloidal compositions may include calcium and MgO, calcium hydroxide, calcium-aluminum silicates, calcium-silicate-hydrate gels, and silica. Concentrations of colloidal suspensions originating from concrete within the repository are considered in PA calculations even though expected to be extremely low.

Distinct interfaces between waters of different salinities and different densities may limit mixing of the water bodies and affect flow and contaminant transport. Such effects have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

The effects of enhanced diffusion across chemical gradients at material boundaries have been eliminated from PAs on the basis of low consequence to the performance of the disposal system.

SCR-6.8 Ecological FEPs

SCR-6.8.1 Plant, Animal, and Soil Uptake

SCR-6.8.1.1

FEP Numbers: W101, W102, and W103
FEP Titles: *Plant Uptake* (W101)
Animal Uptake (W102)
Accumulation in Soils (W103)

SCR-6.8.1.1.1 Screening Decision: SO-R for section 191.13 – W101, W102
SO-C Beneficial for section 191.13 – W103
SO-C for section 191.15 – W101, W102, W103

Plant Uptake, *Animal Uptake*, and *Accumulation in Soils* have been eliminated from compliance assessment calculations for section 191.15 on the basis of low consequence. *Plant Uptake* and *Animal Uptake* in the accessible environment have been eliminated from PA calculations for section 191.13 on regulatory grounds. *Accumulation in Soils* within the controlled area has been eliminated from PA calculations for section 191.13 on the basis of beneficial consequences.

SCR-6.8.1.1.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.8.1.1.3 Screening Argument

The results of the calculations presented in Section 34, "Results of Performance Assessment," show that releases to the accessible environment under undisturbed conditions are restricted to lateral releases through the DRZ at repository depth. Thus, for evaluating compliance with the EPA's individual protection requirements in section 191.15, FEPs that relate to plant uptake, animal uptake, and accumulation in soils have been eliminated from compliance assessment calculations on the basis of low consequence.

PAs for evaluating compliance with the EPA's cumulative release requirements in section 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to plant uptake and animal uptake in the accessible environment have been eliminated from PA calculations on regulatory grounds. Accumulation in soils that may occur within the controlled area would reduce releases to the accessible environment and can, therefore, be eliminated from PA calculations on the basis of beneficial consequence.

SCR-6.8.2 Human Uptake

SCR-6.8.2.1

FEP Numbers: W104, W105, W106, W107, and W108
FEP Titles: *Ingestion* (W104)
Inhalation (W105)
Irradiation (W106)
Dermal Sorption (W107)
Injection (W108)

SCR-6.8.2.1.1 Screening Decision: SO-R
SO-C for section 191.15

Ingestion, *Inhalation*, *Irradiation*, *Dermal Sorption*, and *Injection* have been eliminated from compliance assessment calculations for section 191.15 and Part 191 Subpart C on the basis of low consequence. FEPs that relate to human uptake in the accessible environment have been eliminated from PA calculations for section 191.13 on regulatory grounds.

SCR-6.8.2.1.2 Summary of New Information

No new information has been identified that affects the screening of these FEPs since the CRA-2009.

SCR-6.8.2.1.3 Screening Argument

As described in Section 54, “Scope of Compliance Assessments,” releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite interbeds within the Salado. Because of the bounding approach taken for evaluating compliance with the EPA’s individual protection requirements in section 191.15 and the groundwater protection requirements in Part 191 Subpart C (see Section 54), FEPs that relate to human uptake by ingestion, inhalation, irradiation, dermal sorption, and injection have been eliminated from compliance assessment calculations on the basis of low consequence.

PAs for evaluating compliance with the EPA’s cumulative release requirements in section 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to human uptake in the accessible environment have been eliminated from PA calculations on regulatory grounds.

SCR-7.0 References

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