APPENDIX PA

ATTACHMENT SCR

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ACRONYMS AND ABBREVIATIONS

AMWTP	Advanced Mixed Waste Treatment Plant
BNL	Brookhaven National Laboratory
CAG	Compliance Application Guidance
CARD	Compliance Application Review Document
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CDF	cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
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
EDTA	ethylene diamine tetra-acetate
EPA	Environmental Protection Agency
EP	event and process
ERMS	Electronic Record Management System
FEP	feature, event, and process
FGE	fissile gram equivalent
FLAC	Fast Lagranian Analysis of Continua
FMT	Fracture-Matrix Transport
FSU	Florida State University
H	human
HC	historical and current human activities
HCN	historic, current and near future human activities
LWA	Land Withdrawal Act
MB	marker bed
MgO	magnesium oxide
MPI	Mississippi Potash Inc.
N	natural
NMBMMR	New Mexico Bureau of Mines and Mineral Resources
NORM	naturally occurring radioactive material
PA	performance assessment
PAVT	performance assessment verification test
RH	remote-handled
RTC	Response to Comments Document
SKI	Statens Kärnkraftinspektion
SMC	Salado mass concrete
SNL	Sandia National Laboratories
SO-C	screened-out consequence
SO-P	screened-out probability
SO-R	screened-out regulatory
T	transmissitivity

TDS	total dissolved solids
TRU	transuranic
TSD	Technical Support Document
TWBIR	Transuranic Waste Baseline Inventory Report
UP	undisturbed performance
VOC	volatile organic compound
W	waste and repository-induced
WIPP	Waste Isolation Pilot Plant
WPO	WIPP Project Office

SCR-1.0 INTRODUCTION

The United States Department of Energy (DOE) has developed the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico for the disposal of transuranic wastes generated by defense programs. In May of 1998, the Environmental Protection Agency (EPA) certified that the WIPP would meet the disposal standards (EPA 1998a) established in Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C (EPA 1993), thereby allowing the WIPP to begin waste disposal operations. This certification was based on performance assessment (PA) calculations that were included in the DOE's Compliance Certification Application (CCA). 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 (demonstrate continued compliance with the disposal standards) every five years. As such, the DOE has prepared a Compliance Recertification Application (CRA-2004) which demonstrates that the WIPP continues to comply with EPA's requirements for radioactive waste disposal. The CRA-2004 includes any changes to the WIPP long-term compliance baseline since the CCA.

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 can and should be 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 has also been used for the CRA-2004 and is described in detail in Section 6.2. For the CRA-2004, this process focused on evaluating any new information that may have impacts or present inconsistencies to those screening arguments and decisions presented in the CCA. Changes and updates as a result of this evaluation are described in the *FEPs Reassessment for Recertification Report* (Wagner et al. 2003).

Wagner et al. (2003) concluded that of the original 237 FEPs included in the CCA, 106 have not changed, 120 FEPs required updates to their FEP descriptions and/or screening arguments, and seven of the original baseline FEPs screening decisions required a change from their original screening decision. Four of the original baseline FEPs have been deleted or combined with other closely related FEPs. Finally, two new FEPs have been added to the baseline. These two FEPs were previously addressed in an existing FEP; they have been separated for clarity. Table SCR-1 summarizes the changes in the FEP baseline since the CCA.

Table SCR-1. FEPs Change Summary Since CCA

EPA FEP I.D.	FEP Name	Summary of Change
FEPs Combined with other FEPs		
N17	Lateral ***Dissolution***	Combined with N16, ***Shallow Dissolution.*** N17 removed from baseline.

Table SCR-1. FEPs Change Summary Since CCA - Continued

EPA FEP I.D.	FEP Name	Summary of Change
N19	***Solution Chimneys***	Combined with N20, *Breccia Pipes.* N19 removed from Baseline.
H33	***Flow Through Undetected Boreholes***	Combined with H31, *Natural Borehole Fluid Flow.* H33 removed from baseline.
W38	***Investigation Boreholes***	Addressed in H31, *Natural Borehole Fluid Flow,* and H33, *"Flow Through Undetected Boreholes."* W38 removed from baseline.
FEPs With Changed Screening Decisions		
W50	***Galvanic Coupling***	SO-P to SO-C
W68	***Organic Complexation***	SO-C to UP
W69	***Organic Ligands***	SO-C to UP
H27	***Liquid Waste Disposal***	SO-R to SO-C
H28	***Enhanced Oil and Gas Production***	SO-R to SO-C
H29	***Hydrocarbon Storage***	SO-R to SO-C
H41	***Surface Disruptions***	SO-C to UP (HCN)
New FEPs for CRA		
H58	***Solution Mining for Potash***	Separated from H13, *Potash Mining.*
H59	***Solution Mining for Other Resources***	Separated from H13, *Potash Mining.*

SCR-2.0 BASIS FOR FEATURES, EVENTS, AND PROCESSES SCREENING PROCESS

SCR-2.1 Requirement for Features, Events, and Processes

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 40 CFR § 191.13 (EPA 1993). These requirements state that the DOE must use PA to demonstrate that the probabilities of cumulative radionuclide releases from the disposal system during the 10,000 years 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 EPA at 40 CFR § 194.32 (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 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 WIPP's compliance with the long-term disposal standards.

SCR-2.2 Features, Events, and Processes List Development for the CCA

As a starting point, the DOE assembled a list of potentially relevant FEPs from the compilation developed by Stenhouse et al. (1993) for the Swedish Nuclear Power Inspectorate Statens Kärnkraftinspektion (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 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 avoid the ambiguities caused by the use of a generic list. Restructuring the list did not remove any substantive issues from the discussion. As discussed in more detail in 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 are 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 are represented by the single FEP, ***Disruption Due to Gas Effects***.

- FEPs that are 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. Examples of such FEPs are ***Design Modifications: Canister and Design Modification: Geometry***.

- 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 are represented by the FEP ***Inhalation***.

- FEPs relating to the containment of hazardous metals, volatile organic compounds (VOCs), and other chemicals that are not regulated by 40 CFR Part 191 were not included.

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

These steps resulted in a list of 237 WIPP-relevant FEPs retained for further consideration in the first certification PA. The 237 were screened to determine which would be included in the PA models and scenarios for the CCA.

SCR-2.3 Criteria for Screening of Features, Events, and Processes and Categorization of Retained Features, Events, and Processes

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 exclusions (SO-R), probability (SO-P), or consequence (SO-C). All three criteria are derived from regulatory requirements. FEPs not screened 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 40 CFR 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 40 CFR Part 191 standard and the 40 CFR Part 194 criteria, the EPA considered and made conclusions on the relevance, consequence, and/or probability of occurrence of particular FEPs. In so doing, it allowed some FEPs to be eliminated from consideration.

SCR-2.3.2 Probability of Occurrence of a Feature, Event, and Process Leading to Significant Release of Radionuclides (SO-P)

Low-probability events can be excluded on the basis of the criterion provided in 40 CFR § 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" (EPA 1996a). 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 Features, Events, and Processes (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, 40 CFR § 194.34(a) 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" (EPA 1996a). The DOE has omitted events and processes 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 occurrence of a particular event or process, 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 considered to 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 Undisturbed Performance (UP) Features, Events, and Processes

FEPs classified as UP are accounted for in calculations of undisturbed performance of the disposal system. Undisturbed performance is defined in 40 CFR § 191.12 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" (EPA 1993). The UP FEPs are accounted for in the PA calculations to evaluate compliance with the Containment Requirements in 40 CFR § 191.13. Undisturbed PA calculations are also used to demonstrate compliance with the individual and groundwater protection requirements of 40 CFR § 191.15 and 40 CFR 191 Subpart C, respectively.

SCR-2.3.5 Disturbed Performance (DP) Features, Events, and Processes

The FEPs classified as DP are accounted for only in assessment calculations for disturbed performance. 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 40 CFR § 191.13.

SCR-2.4 Features, Events, and Processes Categories and Timeframes

In the following sections, FEPs are discussed under the categories Natural (N) FEPs, Human-Initiated (H) Events and Processes (EPs), and Waste- and Repository-Induced (W) FEPs. The FEPs are also considered within time frames during which they may occur. Due to the regulatory requirements concerning human activities, two time periods were used when evaluating Human-Initiated EPs. These timeframes were defined as Historical, Current, and Near-Future Human Activities (HCN) and Future Human Activities (Future). These time frames are also discussed in the following section.

SCR-2.4.1 Description of Natural Features, Events, and Processes

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 timeframe. 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 events and processes are included within the screening process.

Consistent with 40 CFR § 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 events and processes 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. Events and processes 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-Initiated Events and Processes

Human-Initiated 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, the severity, and the manner in which to include them in the future predictions.

The scope of PAs is clarified with respect to human-initiated events and processes in 40 CFR § 194.32. At 40 CFR § 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 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 40 CFR § 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 40 CFR § 194.32 relating to the scope of PAs, the DOE has divided human activities into three categories: (1) human activities that are 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 are considered under undisturbed performance, and EPs in the third category lead to disturbed performance conditions. A description of these three categories follows.

1. Historical and current human activities (HC) 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 that are 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 Performance Assessment

Performance assessments 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 40 CFR § 194.32(a), which limits the scope of consideration of future human actions 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 40 CFR § 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 disturbed performance of the disposal system. Consistent with 40 CFR § 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 40 CFR 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 40 CFR § 194.33. The EPA also provides a criterion in 40 CFR § 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. Theses 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 40 CFR § 194.33(b)(1) the EPA states that:

> 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 Event and Processes

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 eliminate completely 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 Features, Events, and Processes

The waste- and repository-induced FEPs are those that relate specifically to the waste material, waste containers, shaft seals, MgO backfill, panel closures, 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 FEATURES, EVENTS, AND PROCESSES BASELINE FOR RECERTIFICATION

The reassessment of FEPs (Wagner et al. 2003) results in a new FEPs baseline for CRA-2004. As discussed in Section SCR.1, 106 of the original 237 WIPP FEPs have not changed. Additionally, 120 FEPs required updates to their FEP descriptions and/or screening arguments. Seven of the original baseline FEPs screening decisions have changed from their original screening decision. Four of the original baseline FEPs have been deleted or combined with other closely related FEPs. Finally, two new FEPs have been added to the baseline. These two FEPs were previously accounted for in a broader FEP. Table SCR-2 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-2 have been addressed by group, due to close similarity with other FEPs within that group. This grouping process was formerly used in the CCA, and also by the EPA in their Technical Support Document (TSD) for §194.32 (EPA 1998c).

Table SCR-2. FEPs Reassessment Results

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N1	***Stratigraphy***	No	No change	UP
N2	***Brine Reservoirs***	No	No change	DP
N3	***Changes in Regional Stress***	No	Additional information added to FEP text, no change to italicized text.	SO-C
N4	***Regional Tectonics***	No	Additional information added to FEP text, no change to italicized text.	SO-C
N5	***Regional Uplift and Subsidence***	No	Additional information added to FEP text, no change to italicized text.	SO-C
N6	***Salt Deformation***	No	No change	SO-P
N7	***Diapirism***	No	No change	SO-P
N8	***Formation of Fractures***	No	Original FEP text revised and replaced, reference to other FEP removed from italicized text	SO-P UP (Repository)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N9	***Changes in Fracture Properties***	No	Original FEP text revised and replaced, reference to other FEP removed from italicized text	SO-C UP (Near Repository)
N10	***Formation of New Faults***	No	Additional information added to FEP text, no change to italicized text.	SO-P
N11	***Fault Movement***	No	Additional information added to FEP text, no change to italicized text.	SO-P
N12	***Seismic Activity***	No	No change	UP
N13	***Volcanic Activity***	No	Italicized text changed, FEP text unchanged	SO-P
N14	***Magmatic Activity***	No	No changes	SO-C
N15	***Metamorphic Activity***	No	No changes	SO-P
N16	***Shallow Dissolution***	No	N16 and N17 (***Lateral Dissolution***) combined, N17 deleted from baseline. FEP text modified and additional information added.	UP
N17	***Lateral Dissolution***	No	Combined with N16 (***Shallow Dissolution***) - Deleted from baseline – see N16	NA
N19	***Solution Chimneys***	No	Combined with N20 and deleted from baseline	NA
N18	***Deep Dissolution***	No	Both italicized and FEP text revised.	SO-P
N20	***Breccia Pipes***	No	N20 and N19 (***Solution Chimneys***) combined, Both italicized and FEP text revised.	SO-P
N21	***Collapse Breccias***	No	Both italicized and FEP text revised.	SO-P

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N22	***Fracture Infills***	No	No changes	SO-C - Beneficial
N23	***Saturated Groundwater Flow***	No	No change	UP
N24	***Unsaturated Groundwater Flow***	No	No change	UP SO-C in Culebra
N25	***Fracture Flow***	No	No change	UP
N27	***Effects of Preferential Pathways***	No	No change	UP UP in Salado and Culebra
N26	***Density effects on Groundwater Flow***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N28	***Thermal effects on Groundwater Flow***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N29	***Saline Intrusion [Hydrogeological Effects]***	No	Reference to other FEPs removed from the italicized text. FEP text unchanged.	SO-P
N30	***Freshwater Intrusion [Hydrogeological effects]***	No	Reference to other FEPs removed from the italicized text. FEP text unchanged.	SO-P
N31	***Hydrological Response to Earthquakes***	No	Reference to other FEPs removed from the italicized text. FEP text unchanged.	SO-C
N32	***Natural Gas Intrusion***	No	Reference to other FEPs removed from the italicized text. FEP text unchanged.	SO-P
N33	***Groundwater Geochemistry***	No	No change	UP
N34	***Saline Intrusion (Geochemical Effects)***	No	FEP N34 and N38 described together. Screening Argument revised and replaced, italicized text revised to remove reference to other FEPs	SO-C

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N38	***Effects of Dissolution***	No	FEP N34 and N38 are described together. Screening Argument revised and replaced, italicized text revised to remove reference to other FEPs	SO-C
N35	***Freshwater Intrusion (Geochemical Effects)***	No	FEP N35, N36 and N37 are described together. Screening Argument revised and replaced, italicized text revised to remove reference to other FEPs	SO-C
N36	***Changes in Groundwater Eh***	No	FEP N35, N36 and N37 are described together. Screening Argument revised and replaced, italicized text revised to remove reference to other FEPs	SO-C
N37	***Changes in Groundwater pH***	No	FEP N35, N36 and N37 are described together. Screening Argument revised and replaced, italicized text revised to remove reference to other FEPs	SO-C
N39	***Physiography***	No	No change	UP
N40	***Impact of a Large Meteorite***	No	No change	SO-P
N41	***Mechanical Weathering***	No	No change	SO-C
N42	***Chemical Weathering***	No	No change	SO-C
N43	***Aeolian Erosion***	No	No change	SO-C
N44	***Fluvial Erosion***	No	No change	SO-C
N45	***Mass Wasting [Erosion]***	No	No change	SO-C
N46	***Aeolian Deposition***	No	No change	SO-C
N47	***Fluvial Deposition***	No	No change	SO-C
N48	***Lacustrine Deposition***	No	No change	SO-C
N49	***Mass Wasting [Deposition]***	No	No change	SO-C

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N50	***Soil Development***	No	Clarification text added to the FEP text	SO-C
N51	***Stream and River Flow***	No	No change	SO-C
N52	***Surface Water Bodies***	No	No change	SO-C
N53	***Groundwater Discharge***	No	No change	UP
N54	***Groundwater Recharge***	No	No change	UP
N55	***Infiltration***	No	No change	UP
N56	***Changes in Groundwater Recharge and Discharge***	No	No change	UP
N57	***Lake Formation***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N58	***River Flooding***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N59	***Precipitation (e.g. Rainfall)***	No	No change	UP
N60	***Temperature***	No	No change	UP
N61	***Climate Change***	No	No change	UP
N62	***Glaciation***	No	No change	SO-P
N63	***Permafrost***	No	No change	SO-P
N64	***Seas and Oceans***	No	No change	SO-C
N65	***Estuaries***	No	No change	SO-C
N66	***Coastal Erosion***	No	No change	SO-C
N67	***Marine Sediment Transport and Deposition***	No	No change	SO-C
N68	***Sea Level Changes***	No	No change	SO-C
N69	***Plants***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N70	***Animals***	No	Reference to other FEPs removed from FEP and italicized text	SO-C
N71	***Microbes***	No	Additional information added to FEP text, reference to other FEPs removed from italicized text.	SO-C (UP - for colloidal effects and gas generation)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N72	***Natural Ecological Deevelopment***	No	No change	SO-C
W1	***Disposal Geometry***	No	No change	UP
W2	***Waste Inventory***	No	No change	UP
W3	***Heterogeneity of Waste Forms***	No	No change	DP
W4	***Container Form***	No	Both italicized and FEP text revised	SO-C
W5	***Container Material Inventory***	No	No change	UP
W6	***Seal Geometry***	No	No change	UP
W7	***Seal Physical Properties***	No	No change	UP
W8	***Seal Chemical Composition***	No	Both italicized and FEP text revised	SO-C Beneficial SO-C
W9	***Backfill Physical Properties***	No	Both italicized and FEP text revised	SO-C
W10	***Backfill Chemical Composition***	No	No change	UP
W11	***Post-Closure Monitoring***	No	Additional information added to FEP text.	SO-C
W12	***Radionuclide Decay and In-Growth***	No	No change	UP
W13	***Heat from Radioactive Decay***	No	No change to Italicized text, new concluding paragraph added to FEP text.	SO-C
W14	***Nuclear Criticality: Heat***	No	No change to Italicized text, additional information added to FEP text.	SO-P
W15	***Radiological Effects on Waste***	No	No change to Italicized text, FEP text revised.	SO-C
W16	***Radiological Effects on Containers***	No	No change to Italicized text, FEP text revised.	SO-C
W17	***Radiological Effects on Seals***	No	No change	SO-C
W18	***Disturbed Rock Zone (DRZ)***	No	No change	UP

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W19	***Excavation-Induced Changes in Stress***	No	No change	UP
W20	***Salt Creep***	No	No change	UP
W21	***Changes in the Stress Field***	No	No change	UP
W22	***Roof Falls***	No	No change	UP
W23	***Subsidence***	No	Minor changes to FEPs text, no changes to italicized text.	SO-C
W24	***Large Scale Rock Fracturing***	No	Minor changes to FEPs text, no changes to italicized text.	SO-P
W25	***Disruption Due to Gas Effects***	No	No change	UP
W26	***Pressurization***	No	No change	UP
W27	***Gas Explosions***	No	No change	UP
W28	***Nuclear Explosions***	No	Reference to other FEPs removed from italicized text, FEP text revised.	SO-P
W29	***Thermal Effects on Material Properties***	No	Additional information added to FEP text, grouped with similar FEPs; italicized text unchanged	SO-C
W30	***Thermally-Induced Stress Changes***	No	Additional information added to FEP text, grouped with similar FEPs; italicized text unchanged	SO-C
W31	***Differing Thermal Expansion of Repository Components***	No	Additional information added to FEP text, grouped with similar FEPs; italicized text unchanged	SO-C
W72	***Exothermic Reactions***	No	Additional information added to FEP text, grouped with similar FEPs; italicized text unchanged	SO-C

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W73	***Concrete Hydration***	No	Additional information added to FEP text, grouped with similar FEPs; italicized text unchanged	SO-C
W32	***Consolidation of Waste***	No	No change	UP
W36	***Consolidation of Seals***	No	No change	UP
W37	***Mechanical Degradation of Seals***	No	No change	UP
W39	***Underground Boreholes***	No	No change	UP
W33	***Movement of Containers***	No	Reference to other FEPs removed from italicized text, FEP text revised	SO-C
W34	***Container Integrity***	No	Reference to other FEPs removed from italicized text, FEP text revised	SO-C Beneficial
W35	***Mechanical Effects of Backfill***	No	Both italicized and FEP text revised.	SO-C
W38	***Investigation Boreholes***	Yes	Encompassed in FEPS H31 and W33, FEP H38 deleted from baseline.	NA
W40	***Brine Inflow***	No	No change	UP
W41	***Wicking***	No	No change	UP
W42	***Fluid Flow Due to Gas Production***	No	No change	UP
W43	***Convection***	No	Reference to other FEPs removed from italicized text, FEP text revised	SO-C
W44	***Degradation of Organic Material***	No	No change	UP
W45	***Effects of Temperature on Microbial Gas Generation***	No	No change	UP
W48	***Effects of Biofilms on Microbial Gas Generation***	No	No change	UP
W46	***Effects of Pressure on Microbial Gas Generation***	No	Reference to other FEPs removed from italicized text, FEP text revised	SO-C

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W47	***Effects of Radiation on Microbial Gas Generation***	No	Reference to other FEPs removed from italicized text, FEP text revised	SO-C
W49	***Gases from Metal Corrosion***	No	No change	UP
W51	***Chemical Effects of Corrosion***	No	No change	UP
W50	***Galvanic Coupling (Within the Repository)***	Yes	Decision changed from SO-P to SO-C. Both italicized and FEP text revised.	SO-C
W52	***Radiolysis of Brine***	No	Both italicized and FEP text revised.	SO-C
W53	***Radiolysis of Cellulose***	No	FEP text revised	SO-C
W54	***Helium Gas Production***	No	Both italicized and FEP text revised.	SO-C
W55	***Radioactive Gases***	No	Reference to other FEPs removed from italicized text, no change to FEP text	SO-C
W56	***Speciation***	No	No change	UP UP in disposal rooms and Culebra. SO-C elsewhere, and beneficial SO-C in cementitious seals
W57	***Kinetics of Speciation***	No	Both italicized and FEP text revised.	SO-C
W58	***Dissolution of Waste***	No	No change	UP
W59	***Precipitation of Secondary Minerals***	No	Both italicized and FEP text revised.	SO-C-Beneficial
W60	***Kinetics of Precipitation and Dissolution***	No	Both italicized and FEP text revised.	SO-C
W61	***Actinide Sorption***	No	No change	UP
W62	***Kinetics of Sorption***	No	No change	UP
W63	***Changes in Sorptive Surfaces***	No	No change	UP
W64	***Effects of Metal Corrosion***	No	No change	UP
W65	***Reduction-Oxidation Fronts***	No	Reference to other FEPs removed from FEP and italicized text	SO-P

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W66	***Reduction-Oxidation Kinetics***	No	No change	UP
W67	***Localized Reducing Zones***	No	Changes to FEPs text, no changes to italicized text.	SO-C
W68	***Organic Complexation***	Yes	Decision changed from SO-C to UP. Both italicized and FEP text revised.	UP
W69	***Organic Ligands***	Yes	Decision changed from SO-C to UP. Both italicized and FEP text revised.	UP
W71	***Kinetics of Organic Complexation***	No	Both italicized and FEP text revised.	SO-C
W70	***Humic and Flvic Acids***	No	No change	UP
W74	***Chemical Degradation of Seals***	No	No change	UP
W76	***Microbial Growth on Concrete***	No	No change	UP
W75	***Chemical Degradation of Backfill***	No	FEP text unchanged, reference to other FEPs removed from FEP and italicized text	SO-C
W77	***Solute Transport***	No	No change	UP
W78	***Colloid Transport***	No	No change	UP
W79	***Colloid Formation and Stability***	No	No change	UP
W80	***Colloid Filtration***	No	No change	UP
W81	***Colloid Sorption***	No	No change	UP
W82	***Suspensions of Particles***	No	No change	DP
W83	***Rinse***	No	No change	SO-C
W84	***Cuttings***	No	No change	DP
W85	***Cavings***	No	No change	DP
W86	***Spallings***	No	No change	DP
W87	***Microbial Transport***	No	No change	UP
W88	***Biofilms***	No	Both italicized and FEP text revised.	SO-C Beneficial

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W89	***Transport of Radioactive Gases***	No	No change to Italicized text, additional information added to FEP text.	SO-C
W90	***Advection***	No	No change	UP
W91	***Diffusion***	No	No change	UP
W92	***Matrix Diffusion***	No	No change	UP
W93	***Soret Effect***	No	No changes	SO-C
W94	***Electrochemical Effects***	No	Both italicized and FEP text revised.	SO-C
W95	***Galvanic Coupling (Outside the Repository)***	No	Reference to other FEPs removed from italicized text, no change to FEP text	SO-P
W96	***Electrophoresis***	No	Both italicized and FEP text revised.	SO-C
W97	***Chemical Gradients***	No	Reference to other FEPs removed from italicized text, additional information added to FEP text.	SO-C
W98	***Osmotic Processes***	No	Reference to other FEPs removed from italicized text, FEP text revised.	SO-C
W99	***Alpha Recoil***	No	Reference to other FEPs removed from italicized text, FEP text revised.	SO-C
W100	***Enhanced Diffusion***	No	Both italicized and FEP text revised.	SO-C
W101	***Plant Uptake***	No	No changes	SO-R
W102	***Animal Uptake***	No	No changes	SO-R
W103	***Accumulation in Soils***	No	No changes	SO-C
W104	***Ingestion***	No	No changes	SO-R
W105	***Inhalation***	No	No changes	SO-R
W106	***Irradiation***	No	No changes	SO-R
W107	***Dermal Sorption***	No	No changes	SO-R
W108	***Injection***	No	No changes	SO-R

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H1	***Oil and Gas Exploration***	No	Updated	SO-C (HCN) DP (Future)
H2	***Potash Exploration***	No	Updated	SO-C (HCN) DP (Future)
H4	***Oil and Gas Exploitation***	No	Updated	SO-C (HCN) DP (Future)
H8	***Other Resources***	No	Updated	SO-C (HCN) DP (Future)
H9	***Enhanced Oil and Gas Recovery***	No	Updated	SO-C (HCN) DP (Future)
H3	***Water Resources Exploration***	No	Both italicized and FEP text revised.	SO-C (HCN) SO-C (Future)
H5	***Groundwater Exploitation***	No	Both italicized and FEP text revised.	SO-C (HCN) SO-C (Future)
H6	***Archaeological Investigations***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H7	***Geothermal***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H10	***Liquid Waste Disposal***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H11	***Hydrocarbon Storage***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H12	***Deliberate Drilling Intrusion***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H13	***Conventional Underground Potash Mining*** ***Formerly Called "Potash Mining"***	No	Name changed from "Potash Mining" to "Conventional Underground Potash Mining." Both italicized and FEP text revised.	UP (HCN) DP (Future)
H14	***Other Resources***	No	Both italicized and FEP text revised.	SO-C (HCN) SO-R (Future)
H15	***Tunneling***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H16	***Construction of Underground Facilities (for Example Storage, Disposal, Accommodation)***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H17	***Archaeological Excavations***	No	Both italicized and FEP text revised.	SO-C (HCN) SO-R (Future)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H18	***Deliberate Mining Intrusion***	No	Both italicized and FEP text revised.	SO-R (HCN) SO-R (Future)
H19	***Explosions for Resource Recovery***	No	Both italicized and FEP text revised.	SO-C (HCN) SO-R (Future)
H20	***Underground Nuclear Device Testing***	No	No changes	SO-C (HCN) SO-R (Future)
H21	***Drilling Fluid Flow***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) DP (Future)
H22	***Drilling Fluid Loss***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) DP (Future)
H23	***Blowouts***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) DP (Future)
H24	***Drilling-Induced Geochemical Changes***	No	Reference to other FEPs removed from FEP and italicized text	UP (HCN) DP (Future)
H25	***Oil and Gas Extraction***	No	No changes	SO-C (HCN) SO-R (Future)
H26	***Groundwater Extraction***	No	No changes	SO-C (HCN) SO-R (Future)
H27	***Liquid Waste Disposal***	Yes	Additional information added to the original FEP text. Screening changed in italicized text from SO-R to SO-C (future).	SO-C (HCN) SO-C (Future)
H28	***Enhanced Oil and Gas Production***	Yes	Additional information added to the original FEP text. Screening changed in italicized text from SO-R to SO-C (future).	SO-C (HCN) SO-C (Future)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H29	***Hydrocarbon Storage***	Yes	Additional information added to the original FEP text. Screening changed in italicized text from SO-R to SO-C (future).	SO-C (HCN) SO-C (Future)
H30	***Fluid-injection Induced Geochemical Changes***	No	Reference to other FEPs removed from FEP and italicized text.	UP (HCN) SO-R (Future)
H31	***Natural Borehole Fluid Flow***	No	H31 and H33 combined. Both FEP text and italicized text revised to include H33.	SO-C (HCN) DP (Future)
H33	***Flow Through Undetected Boreholes***	Yes	Combined with H31 and deleted from FEPs baseline.	NA
H32	***Waste-Induced Borehole Flow***	No	Both FEP text and italicized text revised.	SO-R (HCN) DP (Future)
H34	***Borehole-Induced Solution and Subsidence***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	SO-C (HCN) SO-C (Future)
H35	***Borehole-Induced Mineralization***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	SO-C (HCN) SO-C (Future)
H36	***Borehole-Induced Geochemical Changes***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	UP (HCN) DP (Future)
H37	***Changes in Groundwater Flow Due to Mining***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	UP (HCN) DP (Future)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H38	***Changes in Geochemistry Due to Mining***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	SO-C (HCN) SO-R (Future)
H39	***Changes in Groundwater Flow Due to Explosions***	No	No changes	SO-C (HCN) SO-R (Future)
H40	***Land Use Changes***	No	Reference to other FEPs removed from italicized text, additional information added to FEP text.	SO-R (HCN) SO-R (Future)
H41	***Surface Disruptions***	Yes	Reference to other FEPs removed from italicized text, additional information added to FEP text.	UP (HCN) SO-R (Future)
H42	***Damming of Streams or Rivers***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) SO-R (Future)
H43	***Reservoirs***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) SO-R (Future)
H44	***Irrigation***	No	Reference to other FEPs removed from FEP and italicized text	SO-C (HCN) SO-R (Future)
H45	***Lake Usage***	No	Reference to other FEPs removed from FEP and italicized text, additional information added to FEP text.	SO-R (HCN) SO-R (Future)
H46	***Altered Soil or Surface Water Chemistry by Human Activities***	No	Reference to other FEPs removed from FEP and italicized text.	SO-C (HCN) SO-R (Future)
H47	***Greenhouse Gas Effects***	No	No changes	SO-R (HCN) SO-R (Future)
H48	***Acid Rain***	No	No changes	SO-R (HCN) SO-R (Future)

Table SCR-2. FEPs Reassessment Results — Continued

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H49	***Damage to the Ozone Layer***	No	No changes	SO-R (HCN) SO-R (Future)
H50	***Coastal Water Use***	No	No changes	SO-R (HCN) SO-R (Future)
H51	***Sea water Use***	No	No changes	SO-R (HCN) SO-R (Future)
H52	***Estuarine Water Use***	No	No changes	SO-R (HCN) SO-R (Future)
H53	***Arable Farming***	No	No changes	SO-C (HCN) SO-R (Future)
H54	***Ranching***	No	No changes	SO-C (HCN) SO-R (Future)
H55	***Fish Farming***	No	No changes	SO-R (HCN) SO-R (Future)
H56	***Demographic Change and Urban Development***	No	Reference to other FEPs removed from FEP and italicized text.	SO-R (HCN) SO-R (Future)
H57	***Loss of Records***	No	Additional information added to FEP text, italicized text modified to remove reference to another FEP.	NA (HCN) DP (Future)
H58	***Solution Mining for Potash***	Yes	New FEP, ***Solution Mining*** was contained in various other FEPs – see H13	SO-R (HCN) SO-R (Future)
H59	***Solution Mining for Other Resources***	Yes	New FEP, ***Solution Mining*** was contained in various other FEPs – see H13	SO-C (HCN) SO-C (Future)

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. Table SCR-2 provides information regarding the changes to these FEPs since the CCA. Of the 72 natural FEPs, 32 remain completely unchanged, 38 were updated to include additional information or were edited for clarity and completeness, and two were deleted from the baseline by combining with other more appropriate FEPs. No screening decisions (classifications) for natural FEPs were changed.

SCR-4.1 Geological FEPs

SCR-4.1.1 Stratigraphy

SCR-4.1.1.1 FEP Number: N1 and N2
FEP Title: ***Stratigraphy*** (N1)
Brine Reservoir (N2)

SCR-4.1.1.1.1 Screening Decision: UP

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 is accounted for in PA calculations.

SCR-4.1.1.1.2 Summary of New Information

No new information has been identified for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-4.1.1.1.3 Screening Argument

The ***Stratigraphy*** and geology of the region around the WIPP, including the distribution and characteristics of pressurized ***Brine Reservoirs*** in the Castile Formation (hereafter referred to as the Castile), are discussed in detail in 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 (Section 6.4.2). The presence of brine reservoirs is accounted for in the treatment of inadvertent drilling (Sections 6.4.12.6 and 6.4.8).

SCR-4.1.2 Tectonics

SCR-4.1.2.1 FEP Number: N3, N4, and N5
FEP Title: ***Regional Tectonics*** (N3)
Change in Regional Stress (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 changes 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

The DOE's screening designations for WIPP regional tectonics, changes in regional stress, regional uplift and subsidence appears to be technically valid. DOE described the WIPP site as located in an area with no evidence of significant tectonic activity, and with a low level of stress in the region. 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 hydrocarbon production. Two nearby events (magnitude 3.5, 10/97, and magnitude 2.8, 12/98) are related to rockfalls in the Nash Draw mine and are not tectonic in origin (DOE 1999). These events did not cause any damage at the WIPP. There are no known nearby active faults, and one of the main tectonic features is a slight eastward dip to pre-Cenozoic formations within the basin. There is no geologic evidence of continuing tilting. These studies show short-term benchmark movements consistent with the basin tilt.

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 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 (1948, pp. 120 - 121) 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 (1988, pp. 4 - 14) and the thinning of the Dewey Lake Redbeds (hereafter referred to as the Dewey Lake) reported by 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. (1983, pp. 58 - 60) to be the result of salt deformation rather than regional tectonic processes. According to Muehlberger et al. (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 of regional stress has been inferred from the geological setting of the area (see 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 years continue, the extent of ***Regional Uplift and Subsidence*** over the next 10,000 years would only be about several feet (approximately 1 m). 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 related processes. The screening discussions can be found in CCA Appendix SCR. The information needed for this screening is included here and covers regional tectonic processes such as subsidence and uplift and basin tilting, magmatic processes such as igneous intrusion and events such as volcanism, and 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 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 (Appendix CCA GCR, pp. 3-58 to 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 (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. (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 m/km (75 to 100 ft/mi), has been superimposed on the sedimentary sequence. P.B. 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.

P.B. 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 years 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 (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 years 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 (1991, pp. 348-351) 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 et al. (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 years 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. (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 (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 (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 Wm-2) reported by Blackwell et al. (1991, p. 428) compared with that in the Rio Grande Rift (typically > 80 m Wm-2) reported by Reiter et al. (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 (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 <u>Deformation</u>

SCR-4.1.3.1.1 FEP Number: N6 and N7
FEP Title: ***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 years on a scale severe enough to significantly affect performance of the disposal system has been eliminated from PA calculations on the basis of low probability of occurrence.

SCR-4.1.3.1.1.2 *Summary of New Information*

The DOE presented extensive evidence that some of the evaporites in the northern Delaware Basin have been deformed and 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 (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 years 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. (1996) prepared detailed structure elevation maps of various units from the base of the Castile Formation 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 (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 (Powers 2002) 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 2002). There is no evidence of more recent deformation at the WIPP site based on such maps.

These findings are consistent with the DOE position in the CCA that diapirism can be eliminated from PA calculations on the basis of low probability of occurrence. Although this discussion includes more recent information, the FEPs screening decision remains unchanged.

SCR-4.1.3.1.1.3 *Screening Argument*

SCR-4.1.3.1.1.3.1 *Deformation*

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 Section 2.1.6.1, and further detail is provided in 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 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 years.

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)*

The formation of fractures has been eliminated from PA calculations on the basis of a low probability of occurrence over 10,000 years. The formation of fractures near the repository is accounted for in PA via treatment of the DRZ.

SCR-4.1.3.2.1.2 *Summary of New Information*

The screening argument for formation of fractures has been revised to reflect recent studies. The screening statement has been updated to reflect the formation of fractures near the repository (DRZ).

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 post-depositional processes. Intraformational post-depositional dissolution of the Rustler Formation 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 (ibid., DOE 1996a: Appendix DEF, Section DEF3.2) and Powers and Holt (1999, 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 years.

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).

The argument against developing new fractures within the Salado Formation during the regulatory period via regional stress therefore appears reasonable. Editorial changes for clarity are suggested, as well as separating the two FEPs into discrete arguments. Although the discussion of fracture development has been revised to include more recent information, the screening decision remains unchanged.

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*

The screening argument has been updated with additional information that addresses the treatment of fractures in the near field. The screening decision has not changed.

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 (N3 ***Changes in Regional Stress***; N4 ***Tectonics***; N5 ***Regional Uplift and Subsidence***; N6 ***Salt Deformation***; N7 ***Diapirism***) have been screened out of PA. These processes are not expected to change the character of fractures significantly during the regulatory period.

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

Shallow dissolution (FEP 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; CCA Appendix FAC; Powers and Holt 1999, 2000; Powers 2002) indicates little potential for dissolution at the WIPP site during the regulatory period. Existing fracture properties are expressed through the relationship between Culebra T values and geologic factors at and near the WIPP site (Holt 2002; Holt and Powers 2002). These will be incorporated in PA (see N16, ***Shallow Dissolution***).

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 T 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 Number(s): N10 and N11
FEP Title(s): ***Formation of New Faults*** (N10)
Fault Movement (N11)

SCR-4.1.3.2.3.1 *Screening Decision: SO-P*

The 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 years.

SCR-4.1.3.2.3.2 *Summary of New Information*

No changes have been made to the FEP screening decision. However, the screening argument text was revised to include information on seismic monitoring since the CCA and the nearby rockfalls of non-tectonic origin in potash mines.

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 Section 2.1.5.3). According to Powers et al. (1978, included in 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 (1988, included in CCA Appendix FAC) note that there is displacement of the Rustler, and 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. (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 hydrocarbon production. Two nearby events (magnitude 3.5, 10/97, and magnitude 2.8, 12/98) are related to rockfalls in the Nash Draw mine and are not tectonic in origin (DOE 1999). These events did not cause any damage at the WIPP. 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 years. The stable tectonic setting also allows the ***Formation of New Faults*** within the basin over the next 10,000 years 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 (top of Salado, M1/H1 of the Los Medaños Member, and M2/H2 of the Los Medaños Member) with halite underlie the Culebra Dolomite Member at the site (Powers 2002). 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 2002). Although the distribution of halite in the Rustler is mainly due to depositional facies and syndepositional dissolution (Holt and Powers 1988; Powers and Holt 1999, 2000), the possibility of past or future halite dissolution along the margins cannot be ruled out (Holt and Powers 1988; Beauheim and Holt 1999). 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 2002).

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 years. The stable tectonic setting also allows the ***Formation of New Faults*** within the basin over the next 10,000 years 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 postclosure 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*

No new information has been identified for this FEP. Any changes in the implementation of seismic activity within PA are discussed in Section 6.0.

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 largely depends 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 (1981, 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 (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 and that only minor damage occurred at accelerations up to 0.4 gravities. 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. 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 years 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 years.

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 years (annual probability of occurrence of 10^{-4}) for events producing ground accelerations of 0.1 gravities. Ground accelerations of 0.2 gravities would have an annual probability of occurrence of about 5×10^{16}.

The results of the seismic risk study and the observations of damage in mines due to groundshaking give an estimated annual probability of occurrence of between 10^{-6} and 10^{-8} 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 Section 6.4.5.3); 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 years.*

SCR-4.1.4.1.2 Summary of New Information

No new information has been identified for this FEP. Editorial changes were made to the screening decision to remove reference to other FEPs. No changes have been made to the description or screening argument.

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 years and 0.6 million years) 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 years.

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 has been identified for this FEP. Editorial changes were made to the screening decision to remove reference to other FEPs. No changes have been made to the description or screening argument.

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 Section 2.1.5.4 and 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 years. 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 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 years.*

SCR-4.1.4.2.4.2 *Summary of New Information*

No new information has been identified for this FEP. Editorial changes were made to the screening decision to remove reference to other FEPs. No changes have been made to the description or screening argument.

SCR-4.1.4.2.4.3 *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 years.

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

In the vicinity of the WIPP site, the processes described in CCA Appendix SCR as ***Shallow Dissolution*** (N16) and ***Lateral Dissolution*** (N17) extensively overlap. As a result, N16 and N17 have been combined and N17 has been deleted from the FEPs baseline. FEP N16 has been modified to account for the deletion of N17. For CRA-2004, all of these interrelated processes, and their attendant features, are considered as part of shallow dissolution, which is accounted for in PA calculations.

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 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 Section 2.1.6.2.

SCR-4.1.5.1.4 Shallow Dissolution

In the region around 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, 1985, 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 propagating fracturing 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 transmissivity of the Culebra in the vicinity of the WIPP was commonly attributed to the effects of dissolution of Rustler halite 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 WIPP, the distribution of halite in the Rustler was attributed to depositional and syndepositional processes rather than post-depositional 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, 1986, 1990), and the suite of features in these beds led these investigators (Holt and Powers 1988; Powers and Holt 1990, 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 likely was 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, 1999, 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 T 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 T values for the Culebra as determined through testing of WIPP hydrology wells.

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 T at Culebra wells. The relationship between geological factors, including dissolution of the upper Salado as well as limited dissolution in the Rustler, and Culebra T is being used to evaluate differences between assuming steady-state Culebra heads and changing heads.

Task 1 for AP-088 (Powers 2002) evaluated geological factors, including shallow dissolution in the vicinity of the WIPP site that related to Culebra T. 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 wide) could be defined as the margin of dissolution of the upper Salado in much of the area around 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 T correlates well with depth or overburden, which affects fracture apertures (Powers and Holt 1995, Holt and Powers 2002; Holt 2002). Dissolution of the upper Salado appears to increase T by one or more orders of magnitude (Holt 2002). Because there is no indication of upper Salado dissolution at the WIPP site, Holt (2002) did not include this factor for the WIPP site in estimates of base T values for the WIPP site and surroundings.

There is no new work since the CCA on the distribution of fracture fillings in the Culebra or on dissolution of the fillings. The effects of this process are represented in the distribution of Culebra T values around the WIPP site.

New work regarding shallow dissolution does not change the inclusion of the effects in the T field for the Culebra within PA calculations. The new work provides a firmer basis for understanding the effects of shallow dissolution as represented in PA.

The effects of ***Shallow Dissolution*** (including the impacts of lateral dissolution) have been included in PA calculations.

SCR-4.1.5.2 FEP Number: N17 (removed from baseline)
FEP Title: ***Lateral Dissolution***

SCR-4.1.5.2.1 Summary of New Information

FEP N17 ***Lateral Dissolution*** is so similar to FEP N16 ***Shallow Dissolution*** as features and processes that they are better treated as a single FEP N16, ***Shallow Dissolution***. Therefore, N17 has been deleted from the FEPs baseline and the text for N16 has been modified to address the combination of N16 and N17 into one FEP N16. ***Shallow Dissolution*** is accounted for in PA calculations and encompasses the nature and characteristics of lateral dissolution.

SCR-4.1.5.3 FEP Number: N18, N20 and N21
FEP Title: ***Deep Dissolution*** (N18)
Breccia Pipes (N20)
Collapse Breccias (N21)

SCR-4.1.5.3.1 Screening Decision: SO-P

Deep Dissolution *and the formation of associated features (for example,* ***Solution Chimneys****,* ***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 years.*

SCR-4.1.5.3.2 Summary of New Information

The DOE limited ***Deep Dissolution*** to processes involving dissolution of the Castile or basal Salado Formations and associated features such as ***Breccia Pipes*** (also known as ***Solution Chimneys***) with this process. The DOE found that deep dissolution is a process that may be operating in the Delaware Basin, but the process is limited by the hydraulic and geochemical characteristics of the expected source of water in the Delaware Mountain Group underlying the evaporite formations. Investigations of the WIPP site have not found evidence of specific features (e.g., ***Breccia Pipes, Solution Collapse***, or ***Solution Chimneys***) associated with deep dissolution. The EPA also concluded that the mechanism may be operating in the Delaware Basin, and that there is little evidence of deep dissolution at the WIPP site. The EPA concluded that the rate or magnitude of this process is not high enough that it is likely to threaten integrity of the WIPP over the next 10,000 years. These conclusions appear reasonable. The original description and screening arguments as presented in the CCA remain valid. The FEP discussion has been modified to clarify the arguments and the original screening decision as presented in the CCA has been revised to remove reference to other FEPs.

SCR-4.1.5.3.3 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 Section 2.1.6.2.

SCR-4.1.5.3.4 Deep Dissolution

Deep Dissolution refers to the dissolution of salt or other evaporite minerals in a formation at depth (see 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. (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 (1978, p. 52) and 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 Section 2.1.6.2), some 35 km (20 mi) east-southeast of the WIPP site, has also been interpreted as a ***Solution Chimneys***. Subsidence has occurred there in historical times according to Nicholson and Clebsch (1961, p. 14), suggesting that dissolution at depth is still taking place. Whether this is the result of downwards-percolating surface water or of 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-4.1.5.3.5 Dissolution within the Castile and Lower Salado Formations

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. (1972) as evidence of dissolution. Holt and Powers (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 (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 (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 the Bell Canyon). Additional boreholes (notably WIPP-13, WIPP-32, and DOE-2) and geophysical logging led 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 the Bell Canyon. These irregularities led to localized depositional thickening of the Castile and lower Salado sediments.

SCR-4.1.5.3.6 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-4.1.5.3.7 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 years.

SCR-4.1.5.4 FEP Number: N19 (removed from baseline)
FEP Title: ***Solution Chimneys***

SCR-4.1.5.4.1 Screening Decision: NA

SCR-4.1.5.4.2 Summary of New Information

Solution Chimneys (N19) and ***Breccia Pipes*** (N20) are equivalent as used in the CCA and supporting documents for the WIPP. Neither the DOE nor the EPA discussions supporting the original certification make a clear distinction between the two. These FEPs have been combined and are addressed in FEP N20 ***Breccia Pipes***. The screening arguments have not changed as a result of consolidation.

SCR-4.1.5.5 FEP Number: N22
FEP Title: ***Fracture Infill***

SCR-4.1.5.5.1 Screening Decision: SO-C - Beneficial

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

SCR-4.1.5.5.2 Summary of New Information

No new information has been identified that related to the screening of this FEP. No changes have been made.

SCR-4.1.5.5.3 Screening Argument

SCR-4.1.5.5.3.1 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 (1986, p. 31) and 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 years—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 Features, Events, and Processes

SCR-4.2.1 Groundwater Characteristics

SCR-4.2.1.1 FEP Number: N23, N24, N25 and N27
FEP Title: ***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 the* ***Effects of Preferential Pathways*** *are accounted for in PA calculations.*

SCR-4.2.1.1.2 Summary of New Information

No new information related to the screening of these FEPs has been identified. These FEPs continue to be accounted for in PA.

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 Sections 2.2.1, 6.4.5, and 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 *have 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

The effects of natural density variations on groundwater flow have been screened out on the basis of low consequence. Editorial changes have been made to the FEP description, argument, and screening decision.

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

(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.*

No new information has been identified related to this FEP. Only editorial changes have been made.

SCR-4.2.2.1.2 Screening Argument

The geothermal gradient in the region of the WIPP has been measured at about 30°C (54°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** *has been eliminated from PA calculations on the basis of a low probability of occurrence over 10,000 years.*

SCR-4.2.2.2.2 Summary of New Information

No new information has been identified related to this FEP. Only editorial changes have been made.

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 years. ***Saline Intrusion*** arising from human events such as drilling into a pressurized brine pocket is discussed in FEPs H21 through H24.

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 **Freshwater Intrusion** *have been eliminated from PA calculations on the basis of a low probability of occurrence over 10,000 years.*

SCR-4.2.2.3.2 Summary

No new information has been identified related to this FEP. Only editorial changes have been made.

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). 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 years.

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

SCR-4.2.2.4.1 Screening Decision: SO-C

A **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 has been identified related to this FEP. Only editorial changes have been made.

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 Response 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. (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, or

- 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 indicate that such a buildup has a low probability of occurring over the next 10,000 years (see FEPs N3 and N4).

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, the ***Hydrological Response to Earthquakes*** have 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 a low probability of occurrence over 10,000 years.

SCR-4.2.2.5.2 Summary of New Information

No new information has been identified related to this FEP. Only editorial changes have been made.

SCR-4.2.2.5.2.1 *Screening Argument*

Hydrocarbon resources are present in formations beneath the WIPP (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 years.

SCR-4.3 Subsurface Geochemical Features, Events, and Processes

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 related to the screening of these FEPs has been identified. These FEPs continue to be accounted for in PA.

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 Geochemistr***y is discussed in detail in Sections 2.2 and 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 any of those from the Rustler. Salado and Castile brine geochemistry is accounted for in PA calculations of the actinide source term (Section 6.4.3.4). Culebra brine geochemistry is accounted for in the retardation factors used in PA calculations of actinide transport (see Section 6.4.6.2).

SCR-4.3.1.2 FEP Number(s): N34 and N38
FEP Title(s): ***Saline Intrusion*** (geochemical effects) (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

The conclusion that "No natural events or processes have been identified that could result in saline intrusion into units above the Salado" (DOE 1996a, Appendix SCR) remains valid. The possibility that dissolution might result in an increase in the salinity of low-to-moderate-ionic-strength groundwaters in the Culebra also appears unlikely.

Nevertheless, ***Saline Intrusion*** and dissolution, in the unlikely event that they occur, would not affect the predicted transport of radionuclides in the Culebra because results obtained from laboratory studies (Brush 1996) with saline solutions were largely used to predict radionuclide transport for the CCA PA and the Performance Assessment Verification Test (PAVT). These results will also be used for the CRA-2004 PA.

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 Member of the Rustler Formation 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-Formation or Salado brines into the Culebra as a result of human intrusion, an anthropogenically induced event, was included in the PA calculations for the CCA and the EPA's PAVT, and is included in the CRA-2004 PA. 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 in the event of human intrusion to 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 offsite 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 years, 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 offsite transport pathway, and with 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 saline (Castile and Salado) solutions 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 (1996) and 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 K_ds obtained with the saline solutions were somewhat lower than those obtained with the Culebra fluids. The K_ds recommended by Brush and Storz (1996) were used for the CRA-2004 PA. These K_ds are also based mainly on results obtained with saline solutions.

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 the CCA PA, the PAVT, and the CRA PA implements 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 Number: N35, N36 and N37
FEP Title: ***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 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

The most likely mechanism for (natural) ***Freshwater Intrusion*** into the Culebra, ***Changes in Groundwater Eh***, ***Changes in Groundwater pH*** is (natural) recharge of the Culebra. There is still considerable uncertainty regarding the extent and timing of recharge of the Culebra. If recharge occurs mainly during periods of high precipitation (pluvials) associated with periods of continental glaciation, the consequences of such recharge are probably already reflected in the ranges of geochemical conditions currently observed in the Culebra as a whole, as well as along the likely offsite transport pathway. Therefore, the occurrence of another pluvial during the 10,000-year WIPP regulatory period would have no significant, additional consequence for the long-term performance of the repository. 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 (are already reflected by existing variations in geochemical conditions) is also still valid.

The decision to screenout FEPs N35, N36, and N37 on the basis of low consequence for the long-term performance of the WIPP remains valid. However, the following discussion provides additional justification for this decision. FEPs N35, N36, and N37 are considered together in this discussion because the same process is the most likely cause, and perhaps the only plausible cause, for all three of these events or changes in these important geochemical properties of groundwaters in the Culebra Member of the Rustler Formation. To summarize, the original screening argument for these FEPs has been modified to provide a more robust basis for the low consequence decision, and ***Effects of Dissolution*** (N38) have been removed from this set of FEPs and is now addressed jointly with ***Saline Intrusion*** (N34).

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). 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 due to the effects of dissolution on groundwater chemistry, or due to 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.

The most likely mechanism for (natural) ***freshwater intrusion*** into the Culebra (FEP 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 plutonium 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 mildy 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 of the Culebra. Lambert (1986), Lambert and Carter (1987), Lambert and Harvey (1987), and Lambert (1991) used a variety of stable and radiogenic, isotopic-dating techniques to conclude that the Rustler (and the Dewey Lake Formation) have been closed hydrologic systems for several thousand to a few tens of thousands of years. 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, 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).

The current program to explain the cause(s) of the rising water levels observed in Culebra monitoring wells may elucidate the nature and timing of recharge. However, the justification of this screening decision does not depend on how this issue is resolved. If recharge occurs mainly during periods of high precipitation (pluvials) associated with periods of continental glaciation, the consequences of such recharge are probably already 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 (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 years 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); (3) the studies that quantified the retardation of Th, U, Pu, and Am for the WIPP CCA PA calculations and the EPA's PAVT were carried out under conditions that encompass those observed along the likely Culebra offsite transport pathway (Brush 1996; Brush and Storz 1996); and (4) these studies demonstrated that 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 WIPP regulatory period (Swift 1991 CCA

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

> 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 years after the last glaciations had begun. High-resolution, deep-sea $\delta^{18}O$ data (and other data) reviewed by Servant (2001, Figures 1 and 2) support the conclusion that, although the volume of ice incorporated in continental ice sheets can expand rapidly at the start of a glaciation rapidly, attainment of maximum volume does not occur until a few thousand or a few tens of thousands of years prior to the termination of the approximately 100,000-year glaciations that have occurred during the last 0.5-1 Ma BP. Therefore, it is unlikely that precipitation and recharge will reach their maximum levels during the 10,000-year 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 (are already reflected by existing variations in geochemical conditions) is also still valid.

SCR-4.3.1.4 FEP Number: N38
FEP Title: ***Effects of Dissolution***

SCR-4.3.1.4.1 Screening Decision: SO-C

See discussion in ***Saline Intrusion*** (N34).

SCR-4.4 Geomorphological Features, Events, and Processes

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 has been identified related to this FEP. No changes have been made.

SCR-4.4.1.1.3 Screening Argument

Physiography and geomorphology are discussed in detail in Section 2.1.4, and are accounted for in the setup of the PA calculations (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 years.*

SCR-4.4.1.3 Summary of New Information

No new information has been identified related to this FEP. No changes have been made.

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 (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 years (equivalent to about 2×10^{-13} impacts per square kilometer per year). Using observations from the Canadian Shield, Hartmann (1965, p. 161) estimated a frequency of between 0.8×10^{-13} and 17×10^{-13} per square kilometer per year for impacts causing craters larger than 1 km (0.6 mi). Frequencies estimated for larger impacts in studies reported by Grieve (1987, p. 263) can be extrapolated to give a rate of about 1.3×10^{-12} per square kilometer per year 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 (1987) would correspond to an overall rate of about 1 per 1,000 years on the basis of a random distribution.

Assuming the higher estimated impact rate of 17×10^{-13} impacts per square kilometer per year 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 year for a direct hit above the repository. This impact frequency is several orders of magnitude below the screening limit of 10^{-4} per 10,000 years provided in 40 CFR § 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 CCA Appendix SCR, Figure SCR-1. The area within which a meteorite could impact the repository is calculated by

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

Where

L = length of the repository footprint (kilometers),
W = width of the repository footprint (kilometers),
D = diameter of the impact crater (kilometers), and
S_D = area of the region where the crater would disrupt the repository (square kilometers).

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 (1987, p. 257) derived the following distribution function:

$$F_D \propto D^{-18} \qquad (2)$$

where

F_D = frequency of impacts resulting in craters larger than D (impacts per square kilometer per year).

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

$$FD = \int_{D}^{\infty} f\,(D)\,d\,D \qquad (3)$$

and

$$f\,(D) = F_1 \times 1.8 \times D^{-28}, \qquad (4)$$

where

F_1 = frequency of impacts resulting in craters larger than 1 km (impacts per square kilometer per year), and

$f(D)$ = frequency of impacts resulting in craters of diameter D (impacts per square kilometer per year).

The overall frequency of meteorite impacts that could disrupt or fracture the repository is thus given by

$$N = \int_{2h}^{\infty} f\,(D) \times S_D\, dD, \qquad (5)$$

Where

h = depth to repository (kilometers),

N = frequency of impacts leading to disruption of the repository (impacts per year), and

$$N = 1.8F_1\left[1.8\ LW(2h)^{-18} + 0.8(L+W)(2h)^{-0.8} - 0.2(2h)^{0.2}\right] \qquad (6)$$

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 per square kilometer per year, then Equation (6) gives a frequency of approximately 1.3×10^{-11} impacts per year for impacts disrupting the repository. If impacts are randomly distributed over time, this corresponds to a probability of 1.3×10^{-7} over 10,000 years.

Similar calculations have been performed that indicate rates of impact of between 10^{-12} and 10^{-13} per year 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 years.

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 years.

SCR-4.4.1.5 FEP Number: N41 and N42
FEP Title(s): ***Mechanical Weathering*** (N41)
Chemical Weathering (N42)

SCR-4.4.1.5.1 Screening Decision: SO-C

The effects of **Chemical 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 has been identified related to these FEPs. No changes have been made.

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 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 Number: N43, N44 & N45
FEP Title: ***Aeolian Erosion*** (N43)
Fluvial Erosion (N44)
Mass Wasting (N45

SCR-4.4.1.6.1 Screening Decision: SO-C

The effects of **Fluvial and Aeolian Erosion and Mass W asting** *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 related to the screening of these FEPs. No changes have been made.

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 cm [13 in.] per year) 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 year 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 years.

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 years.

Erosion from wind, water, and mass wasting will continue in the WIPP region throughout the next 10,000 years 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*** and ***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 has been identified related to the screening of this FEP. Editorial changes have been made.

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. (1989, pp. 2-4) at 410,000 to 510,000 years old, is present in collapse blocks, indicating some growth of Nash Draw in the late Pleistocene. Localized gypsite spring deposits about 25,000 years old occur along the eastern flank of Nash Draw, but the springs are not currently active. The Berino soil, interpreted as 333,000 years 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 years.

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 Features, Events, and Processes

SCR-4.5.1 Depositional Processes

SCR-4.5.1.1 FEP Number: N46, N47, N48 and N49
FEP Title: ***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****,* ***Fluvial****,* ***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 has been identified related to the screening of these FEPs. No changes have been made.

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 years 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***, ***Fluvial***, ***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 has been identified related to the screening of this FEP. No changes have been made.

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; and Bachman 1974, 1981, and 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*** have 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 has been identified related to the screening of this FEP. No changes have been made.

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, 1981, and 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 Number: N53, N54, and N55
FEP Title: ***Groundwater Discharge*** (N53)
Groundwater Recharge (N54)
Infiltration (N55)

SCR-4.5.3.1.1 Screening Decision: UP

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

SCR-4.5.3.1.2 Summary of New Information

No new information has been identified for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-4.5.3.1.3 Screening Argument

The groundwater basin described in 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 (Sections 2.2.1.4 and 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 information has become available that would change the screening decision for this FEP. Changes in the implementation (if any) of this FEP within PA are addressed in Chapter 6.0. This FEP has been separated from N57 and N58 for editorial purposes.

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 years (see FEPs N59 to N63). Groundwater basin modeling (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 (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 years after any decrease in recharge. Under the anticipated changes in climate over the next 10,000 years, 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 (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 (Section 6.4.9).

SCR-4.5.3.3 FEP Number: N57 & N58
FEP Title: ***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

The original text in CCA Appendix SCR has been modified only to remove reference to other FEPs. No substantive changes have been made to the FEP descriptions, screening arguments, or screening decision.

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 years. 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 Events and Processes

SCR-4.6.1 Climate and Climate Changes

SCR-4.6.1.1 FEP Number: N59 and N60
FEP Title: ***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 has been identified for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-4.6.1.1.3 Screening Argument

The climate and meteorology of the region around the WIPP are described in, Section 2.5.2. Precipitation in the region is low (about 33 cm (13 in.) per year) 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 (Section 6.4.9 and Appendix PA, Attachment PAR).

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 has been identified for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-4.6.1.2.3 Screening Argument

Climate Changes are instigated by changes in the earth's orbit, which affect the amount of insolation, 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 years 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). 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 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 (Section 6.4.9 and Appendix PA, Attachment PAR).

SCR-4.6.1.3 FEP Number: N62 and N63
FEP Title: ***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 years.*

SCR-4.6.1.3.2 Summary of New Information

No new information has been identified related to the screening of these FEPs. No changes have been made.

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 years is highly unlikely (Imbrie and Imbrie 1980, 951).

Thus, ***Glaciation*** has been eliminated from PA calculations on the basis of low probability of occurrence over the next 10,000 years. 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 years.

SCR-4.7 Marine Features, Events, and Process

SCR-4.7.1 Seas, Sedimentation, and Level Changes

SCR-4.7.1.1 FEP Number(s): N64 and N65
FEP Title(s): ***Seas and Oceans*** (N64)
Estuaries (N65)

SCR-4.7.1.1 Screening Decision: SO-C

*The effects of **Estuaries**, seas, and oceans have has 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 has been identified related to this FEP. No changes have been made.

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 Number(s): N66 and N67
FEPs Title(s): ***Coastal Erosion*** (N66)
Marine Sediment Transport and Deposition (N67)

SCR-4.7.1.2.1 Screening Decision: SO-C

The effects of **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 has been identified related to these FEPs. No changes have been made.

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 has been identified relating to the screening of this FEP. No changes have been made.

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 (1986, p. 138). This can have marked effects on coastal aquifers. During the next 10,000 years, 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 (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 Features, Events, and Process

SCR-4.8.1 Flora and Fauna

SCR-4.8.1.1 FEP Number(s): N69 and N70
FEP Title(s): ***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 has been identified related to the screening of these FEPs. Only editorial changes have been made.

SCR-4.8.1.1.3 Screening Argument

The terrestrial and aquatic ecology of the region around the WIPP is described in 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 has 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

Microbes can be important in soil development. As dissolved actinide elements are introduced to the Culebra, it is possible that those dissolved actinides can sorb onto ***Microbes***. However, due to the size effect, ***Microbes*** will be rapidly filtered out of the advective flow domain; hence, the effect of ***Microbes*** on radionuclide transport in the Culebra will be insignificant. The original screening decision remains valid. Additional information has been included to support the screening argument.

SCR-4.8.1.2.3 Screening Argument

Microbes are presumed to be present with the thin soil horizons. Gillow et al. (2000) characterized the microbial distribution in Culebra groundwater at the WIPP site. Culebra groundwater contained $1.51 \pm 1.08 \times 10^5$ cells/ml. The dimension of the cells are 0.75 μm in length and 0.58 μm in width, right at the upper limit of colloidal particle size. Gillow et al. (2000) also found that at pH 5.0, Culebra denitrifier CDn ($0.90 \pm 0.02 \times 10^8$ cells/ml) removed 32 percent of the uranium added to sorption experiments, which is equivalent to 180 ± 10 mg U/g of dry cells. Another isolate from WIPP (Halomonas sp.) ($3.55 \pm 0.11 \times 10^8$ cells/ml) sorbed 79 percent of the added uranium. Due to their large sizes, microbial cells as colloidal particles will be rapidly filtered out in the Culebra formation. Therefore, the original FEP screening decision that ***Microbes*** in groundwater have an insignificant impact on radionuclide transport in the Culebra formation remains valid. A similar conclusion has also been arrived for Sweden repository environments (Pedersen 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 has been identified related to the screening of this FEP. No changes have been made.

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 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-INITIATED EPS

The following section presents screening arguments and decisions for human-initiated EPs. Table SCR-2 provides summary information regarding changes to human-initiated EPs since the CCA. Of the 57 human-initiated EPs, 13 remain unchanged, 39 were updated with new information or were edited for clarity and completeness, 4 screening decisions were changed, 1

EP was deleted from the baseline by combining with other more appropriate EPs, and 2 EPs were added.

SCR-5.1 Human Induced Geological Events and Process

SCR-5.1.1 Drilling

SCR-5.1.1.1 FEP Number: H1, H2, H4, H8, and H9
FEP Title: ***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 G as Exploitation, Drilling for Other Resources,*** *and* ***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 disturbed performance scenarios through incorporation of the rate of future drilling as specified in 40 CFR § 194.33.*

SCR-5.1.1.1.2 Summary of New Information

Regulations require that drilling for resources in the future be considered in PA calculations. As such, deep drilling associated with ***Oil and Gas Exploration, Potash Exploration, Oil and Gas Exploration*** drilling for ***Other Resources***, and ***Enhanced Oil*** *and* ***Gas Recovery*** in the future is accounted for in the PA in DP scenarios via the drilling rate as calculated by the method prescribed by the EPA. For HCN time frames, deep drilling for ***Oil and Gas Exploration, Potash Exploration, Oil and Gas Exploitation,*** and drilling for ***Other Resources*** has been screened out based on consequence. Additionally, ***Drilling for the Purposes of Enhanced Oil*** *and* ***Gas Recovery*** has been screened out based on consequence because the process of drilling does not vary depending on the intended use of the borehole, be it for resource recovery, reservoir stimulation, or for other purposes such as geologic characterization and exploration. The screening decision of SO-C for HCN for these FEPs is largely based on the screening of FEPs H21 ***Drilling Fluid Flow***, H22 ***Drilling Fluid Loss***, and H23 ***Blowouts***. Because these activities are currently taking place, and will not occur within the land withdrawal boundary during the current time period nor in the near future (due to active institutional controls), the only possible impact to the repository could be from ***Drilling Fluid Flow, Fluid Loss, or Blowout*** in boreholes outside the WIPP land withdrawal boundary. The specific effects are discussed in detail within the screening discussions for FEPs H21, H22, and H23.

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. (1978) (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 (NMBMMR) performed a reevaluation of the mineral resources at and within 1.6 km (1 mi) around the WIPP site. While some resources do exist at the WIPP site, for the HCN timeframes, such drilling is assumed to only occur outside the WIPP site boundary. This assumption is based on current federal ownership and management of the WIPP during operations, and assumed effectiveness of institutional controls for the 100-year 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 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 due to transfer of rights and controls 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.

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 H58, solution mining. 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 WIPP consists of single-point injectors, rather than broad, grid-type waterflood projects (Hall et al. 2003). 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 H21 ***Drilling***

Fluid Flow, H22 ***Drilling Fluid Loss***, and H23 ***Blowouts***. Discussion on the effects subsequent to drilling a borehole for the purpose of enhancing oil and gas recovery is discussed in FEP H28, ***Enhanced Oil and Gas Production***.

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, where low consequence screening arguments are provided.

SCR-5.1.1.1.4 Future Human EPs

Criteria in 40 CFR § 194.33 require the DOE to examine the historical rate of drilling for resources in the Delaware Basin. Thus, consistent with 40 CFR § 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 Appendix DEL, Appendix DATA; and Chapter 6.3.2).

SCR-5.1.1.2 FEP Number(s): H3 and H5
FEP Title(s): ***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 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

In the screening of FEPs conducted for the CCA, FEP H3 and H5 were screened out based on low consequence (SO-C) for the long-term performance of the WIPP. The CCA screening decision and argument applied to both the HCN and future time periods and remain valid for the CRA; however, additional justification for this conclusion has been provided.

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 Formation and thus 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. Thus, the screening argument 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 Delaware Basin Drilling Surveillance Program (DBDSP) continues to collect drilling data related to water resources, as well as other shallow drilling activities. As shown in the DBDSP 2002 Annual Report (DOE 2002), 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, a decrease of 35 wells (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 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 CCA Section 2.3.1.3. The distribution of groundwater wells in the Delaware Basin is included in 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 40 CFR § 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 years. 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 40 CFR § 194.33(b)(4), the DOE accounts for this drilling through the use of the historical record of shallow 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.

SCR-5.1.1.3 FEP Number: H6, H7, H10, H11, and H12
FEP Title: ***Archeology*** (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 ***Archeology, 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

Based on current Delaware Basin data (Appendix DATA, Attachment A), the regulatory exclusion based on the "future states assumption" continues to be valid; i.e., no drilling for geothermal, archeological, liquid waste disposal, or hydrocarbon storage has occurred. Only editorial changes have been made.

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 40 CFR § 194.25(a), 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); 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, 66-67). Therefore, drilling of boreholes for the explicit purpose of ***Hydrocarbon Storage*** has not occurred.

Consistent with 40 CFR § 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-5.1.1.3.4 Future Human EPs

Consistent with 40 CFR § 194.33 and the future states assumptions in 40 CFR § 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 years, 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 40 CFR § 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

The name of this FEP has been changed to more specifically identify the mining process. Previously, H13 was generically titled ***Potash Mining***, which broadly included all mining mechanisms and techniques such as conventional, strip or surface, and solution mining. ***Solution Mining*** for potash is addressed in FEP H58, and ***Solution Mining for brine***, ***other Minerals***, or for the ***Creation of Storage Cavities***, is addressed in FEP H59.

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 Section 2.3.1). Potash is mined by conventional techniques extensively 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 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 40 CFR § 194.32 (b), and as further described in the Supplementary

Information to 40 CFR 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

Since the CCA, no changes in the resources sought via mining have occurred. Therefore, the screening decision for mining for other resources have not changed. Minimal changes to the screening argument have been made for clarity and completeness.

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 quality similar to that currently mined elsewhere in the Delaware Basin. Future ***M ining for Other Resources*** has been eliminated from PA calculations on regulatory grounds.

SCR-5.1.2.3 FEP Number: H15 and H16
FEP Title: ***Tunneling*** (H15)
Construction of Underground Facilities (H16)

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

*Consistent with 40 CFR § 194.33(b)(1), near-future human-initiated events and processes relating to **Tunneling** into the WIPP excavation and **construction of underground facilities** have been eliminated from PA calculations on regulatory grounds. Furthermore, consistent with 40 CFR § 194.33(b)(1), future human-initiated 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

This FEP has been screened out according to the regulatory criteria in 40 CFR 194.25 (a) (characteristics of the future remain what they are at the time the compliance application). Potash mining, which includes ***Tunneling***, has taken place in the Northern Delaware Basin and potash mining is accounted for in PA calculations. The FEP description, screening argument, and screening decision remain unchanged.

SCR-5.1.2.3.3 Screening Argument

No ***Tunneling*** or ***Construction of Underground Facilities*** (for example, storage, disposal, accommodation [that is, dwellings]) has taken place in the Delaware Basin. Mining for potash occurs (a form of ***Tunneling***), but is addressed specifically in FEP H-13. 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).

On April 26, 2001, the DOE formally requested approval the installation of the OMNISita astrophysics experiment in the core storage alcove of the WIPP underground. The purpose of the project is to develop a prototype neutrino detector to test proof of concept principles and measure background cosmic radiation levels within the WIPP underground. EPA approved the request on August 29, 2001. This project does not require additional ***Tunneling*** or excavation beyond the current repository footprint, and therefore does not impact the screening argument for this FEP.

Because ***Tunneling*** and ***Construction of Underground Facilities*** (other than WIPP) have not taken place in the Delaware Basin, and consistent with the future states assumptions in 40 CFR § 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

The original description for this FEP and screening argument remain valid; only editorial changes have been made.

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 40 CFR § 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 40 CFR § 194.33(b)(1), near-future human-initiated EPs relating to **Deliberate Mining Intrusion** *into the WIPP excavation have been eliminated from PA calculations on regulatory grounds. Furthermore, consistent with 40 CFR § 194.33(b)(1), future human-initiated 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 changes have been to this FEP.

SCR-5.1.2.5.3 Screening Argument

Consistent with 40 CFR § 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

The original screening argument and decision for this FEP remain valid. Additional text has been added to describe the past use of explosives in potash mining in the Delaware Basin. This additional information is provided for completeness, and does not affect the screening argument or decision.

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 H39.

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

Neither small-scale nor regional-scale explosive techniques to enhance formation 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 years 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 40 CFR § 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 has been identified related to this FEP. No changes have been made.

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 m^3 (950,000 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. 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 40 CFR § 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 Events and Processes

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 is available for this FEP. However, the screening argument has been revised for clarity and editorial purposes.

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 (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, 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.

A future borehole that is drilled through a disposal room wall, but does not intersect waste, could penetrate a brine reservoir underlying the waste disposal region. Such an event would depressurize the brine reservoir to some extent, and thus would affect the consequences of any subsequent intersections of the reservoir. The possibility for a borehole to depressurize a brine reservoir underlying the waste disposal region 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.

In evaluating the potential consequences of **Drilling Fluid Loss** to a waste panel, two types of drilling events need to be considered – those that intercept pressurized fluid in underlying formations such as the Castile (defined in CCA 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. As discussed in CCA Section 6.4.12.6, of boreholes that intersect a waste panel in the future, 8 percent are assumed to be E1 events and 92 percent are E2 events. 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 may not be noticed and may 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 CCA 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.

For boreholes that do not intersect pressurized brine reservoirs 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-5.2.1.2 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 is available for this FEP. However, the screening argument has been revised for clarity and editorial purposes.

SCR-5.2.1.2.3 Screening Argument

Drilling Fluid lLoss 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.

The consequences of **Drilling Fluid Loss** into waste panels in the future is accounted for in PA calculations for E1 and 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 under pressurized 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 under pressurized 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

No new information is available for this FEP. However, the screening argument has been revised for clarity and editorial purposes.

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 passive and active institutional controls 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.

The consequences of ***Blowout*** in the future 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 Section 2.2.1.3) and in the Salado above the WIPP horizon (Section 2.2.1.2.2). 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, 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

(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 primarily depend 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 (1996a) analyzed the potential effects of such interconnections in the future within the controlled area 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 is available for this FEP. However, the screening argument has been revised for clarity and editorial purposes.

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, 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*

Radionuclide migration rates are governed by the coupled effects of hydrological and geochemical processes (see discussions in FEPs W77 through W100). 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 Sections 6.4.3.6 and 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 Section 6.4.6.2. The sorption model comprises an equilibrium, sorption isotherm approximation, employing distribution coefficients (Kds) applicable to dolomite in the Culebra (Appendix PA, Attachment MASS, Section MASS.15.2; and PAVT). The CDFs of distribution coefficients used are derived from a suite of experimental studies that include measurements of K_ds for actinides in a range of chemical systems including Culebra and Castile brines, Culebra brines, and Salado brines. Therefore, 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 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 years (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. 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*** 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 *Geochemical Effects of Drilling-Induced Flow*

Drilling Fluid Loss to a waste panel could modify the chemistry of disposal room brines in a manner that would affect the solubility of radionuclides and the source term available for subsequent transport from the disposal room. The majority of drilling fluids used are likely to be locally derived, and their bulk chemistry will be similar to fluids currently present in the disposal system. In addition, the presence of the MgO chemical conditioner in the disposal rooms will buffer the chemistry across a range of fluid compositions, as discussed in detail in Appendix PA, Attachment SOTERM. Furthermore, for E1 drilling events, the volume of Castile brine that flows into the disposal room will be greater than that of any drilling fluids; Castile brine chemistry is accounted for in PA calculations. Thus, the effects on radionuclide solubility of ***Drilling Fluid Loss*** to the disposal room have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

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 result in geochemical changes in the receiving units, and thus alter radionuclide migration rates in these units through their effects on colloid transport and sorption.

The repository and its contents provide the main source of colloids in the disposal system. Thus, colloid transport in the Culebra within the controlled area as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region are accounted for in PA calculations, as described in Sections 6.4.3.6 and 6.4.6.2.1. 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 ***Drilling Fluid Loss*** associated with boreholes that 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, sorption within the Culebra is accounted for in PA calculations. The sorption model used incorporates the effects of changes in sorption in the Culebra as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region.

Consistent with the screening discussion in FEPs H21, H22, and H23, the effects of changes in sorption in the Dewey Lake inside the controlled area as a result of drilling-induced flow associated with boreholes that 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.

SCR-5.2.1.4.3.5 *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 40 CFR § 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, 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-5.2.1.4.3.6 *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, 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, 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, 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 historical, current, near-future, 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 Number(s): H25 and H26
FEP Title(s): ***Oil and Gas Extraction***
Groundwater Extraction

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

HCN ***Groundwater, 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, 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 has been identified related to the screening of these FEPs. Delaware Basin monitoring information (see Appendix DATA, Attachment A) does not indicate any changes in oil, gas, or water extraction that would require modification to these screening arguments or decisions. No changes have been made.

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 Section 2.2.1.4.2.1). Also, water has 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. No water wells in other areas in the vicinity of the WIPP are expected to be drilled in the near future because of the high concentrations of total dissolved solids in the groundwater.

If contaminated water intersects a well while it is producing, then contaminants could be pumped to the surface. Consistent with the containment requirements in 40 CFR § 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 40 CFR § 191.15. As discussed in Chapter 8.0, under undisturbed conditions, there are no calculated radionuclide releases to units containing producing wells.

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 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-year 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 (1996b), using an analytical solution for Darcian fluid flow in a continuous porous medium. Wallace (1996b) showed that such a well pumping at about 0.5 g (1.9 L) per minute for 10,000 years 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 years. 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 40 CFR § 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 Number(s): H27, H28 and H29
FEP Title(s): ***Liquid Waste Disposal*** (H27)
Enhanced Oil and Gas Production (H28)
Hydrocarbon Storage (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. 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. **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

Fluid injection modeling conducted since the CCA has demonstrated that injection of fluids will not have a significant effect upon the WIPP's ability to contain radioactive materials (Stoelzel and Swift 1997). The results of this modeling justify changing the screening decision for these FEPs from SO-R to SO-C for the future timeframe. Neither hydraulic fracturing nor waterflooding conducted in wells outside the controlled area have the potential to affect the disposal system in any significant way. The screening argument for this FEP has been updated to include references and conclusions from Steolzel and Swift. The hydrological effects of HCN, and future ***Hydrocarbon Storage*** (H29) have been screened out on the basis of low consequence. Only one hydrocarbon (gas) storage facility is operating in the Delaware Basin, and it is too far away to have any effect on groundwater at the WIPP under any circumstances. No changes have been made to the FEP description, although the screening decision for the future time period has been changed from SO-R to SO-C; the screening argument has been modified slightly to include citation of a recent survey.

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*** (by-products 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 ***Carbon Dioxide*** 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 WIPP (Melzer 2003). Even if ***Carbon Dioxide*** 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; CCA Appendix DATA, 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 years 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 2100 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 1400 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. A recent report (Hall et al. 2003) concludes that injection well operations near WIPP have a very low failure rate, and that failures, although rare, are remedied quickly.

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 (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 (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 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. Also, the boreholes were assumed to be plugged immediately above the Salado (consistent with the plugging configurations described in 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-year simulated disposal period. In this time, approximately 50 m^3 (1765.5 ft^3) of brine entered the anhydrite interval at the horizon of the waste disposal region. For the next 200 years the boreholes were assumed to be abandoned (with open-hole permeabilities of 1×10^{-9} m^2 (4×10^{-8} in.)). Cement plugs (of permeability 1×10^{-17} m^2 (4×10^{-16} in.)) 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 Section 6.4.7.2), and the simulation was continued until the end of the 10,000-year 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 undisturbed performance 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 (1997) expanded on Stoelzel and O'Brien's (1996) work by considering injection for a longer period of time (up to 150 years) 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 (1996). Rather than repeat the conservative and bounding approach used by Stoelzel and O'Brien (1996), 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 MB139 (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 (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 MB139 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 MB138 and MB139.

No flow entered MB139, 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 $1 \times 10^{-12.5}$ 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 MB139 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 years of leakage through a fully degraded cement sheath or 10 years 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 (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 by-products 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 (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 Section 2.3.1.1). The effects of such potash mining are accounted for in calculations of undisturbed performance 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). 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 (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

$$\bar{v} - -\frac{k}{\mu}[\nabla p - \rho \bar{g}], \tag{7}$$

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

$$\bar{v} = -K\left[\nabla H_f + \frac{\Delta\rho}{\rho_f}\nabla E\right], \tag{8}$$

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

$$\mathrm{DFR} = \frac{\Delta\rho\left|\nabla E\right|}{\rho_f\left|\nabla H_f\right|} \tag{9}$$

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° or 8 m/km (26 ft/mi) to the east (Davies 1989, p. 42). According to 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 kg/m^3 (998 to 1,158 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). 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, 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.

Nonlocally 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 40 CFR § 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 dDisposal (by-products 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*** have been eliminated from PA calculations on the basis of low consequence.

SCR-5.2.1.7 FEP Number: H30
FEP Title: ***Fluid Injection-Induced Geochemical Changes***

SCR-5.2.1.7.1 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. ***Liquid Waste dDisposal****,* ***Enhanced Oil and Gas Production****, and* ***Hydrocarbon Storage*** *involving future boreholes have been eliminated from PA calculations on regulatory grounds.*

SCR-5.2.1.7.2 Summary of New Information

No new information regarding this FEP has been identified. The screening argument has been enhanced; the screening decisions have not changed.

SCR-5.2.1.7.3 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-5.2.1.7.3.1 *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). 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, 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-5.2.1.7.3.2 *Future Human EPs*

Consistent with 40 CFR § 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 dDisposal*** (by-products 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-5.2.1.8 FEP Number: H31 and H33
FEP Title: ***Natural Borehole Fluid Flow*** (H31)
Flow Through Undetected Boreholes (H33)

SCR-5.2.1.8.1 Screening Decision: SO-C (HCN)
SO-C (Future, holes not penetrating waste panels)
DP (Future, holes through waste panels)

The effects of natural 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 flow through a future borehole that intersects a waste panel is accounted for in PA calculations. The effects of natural borehole 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-5.2.1.8.2 Summary of New Information

Natural Borehole Fluid Flow and ***Flow Through Undetected Boreholes*** have been combined because knowledge of a borehole's existence has no impact on its effects. ***Flow Through Undetected Boreholes*** has been deleted from the baseline and the description of ***Natural Borehole Fluid Flow*** was changed to include unknown boreholes. The screening argument has been modified to simplify and improve clarity.

SCR-5.2.1.8.3 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-5.2.1.8.3.1 *Historical, Current, and Near-Future Human EPs*

SCR-5.2.1.8.3.2 *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 we know of their existence or not, hence* **Flow Through Undetected Boreholes** *and* **Flow Through Undetected Boreholes** *can be evaluated together.*

SCR-5.2.1.8.3.3 *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-5.2.1.8.3.4 *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 years, a large number of deep boreholes have been drilled within and around the controlled area (see 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 (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 64×10^6 pascals (9,600 psi), with permeability of about 2×10^{-14} m^2 (2.1×10^{-13} 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 (35×10^6 pascals (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 (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 (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. He further conservatively assumed that the pressure in the Atoka would not have been depleted by production before the well was plugged and abandoned. He also 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 0.88×10^6 pascals (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 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 Section 6.4.9 (and 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 percent probability, and the range from 1.50 to 2.25 having a 25 percent 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-5.2.1.8.3.5 *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 percent.

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-5.2.1.8.3.6 *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 (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 Sections SCR.5.2.1 (FEPs H27, H28, and H29), shows that the density effect is of low consequence to the performance of the disposal system.

SCR-5.2.1.8.3.7 *Future Human EPs*

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 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 Section 6.4.7.2). 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-5.2.1.8.3.8 *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 Flow*** through such a borehole is accounted for in PA calculations (see 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 WIPP PA Department (1991, B-26 to B-27), which examined single-phase flow and transport between the waste panels and a borehole intersecting MB139 outside the DRZ. The analysis assumed an in situ pressure of 11 megapascals in MB139, a borehole pressure of 6.5 megapascals (975 psi) (hydrostatic) at MB139, and a constant pressure of 18 megapascals (2,700 psi) as a source term in the waste panels representing gas generation. Also, MB139 was assigned a permeability of approximately 3×10^{-20} m^2 (3.2×10^{-19} ft^2) and a porosity of 0.01 percent. The disturbed zone was assumed to exist in MB139 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 percent. 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-5.2.1.8.3.9 *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-year regulatory period, a large number of deep boreholes could be drilled within and around the controlled area (see 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-5.2.1.8.3.10 *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 (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 where this effect is screened out on the basis of low consequence.

SCR-5.2.1.9 FEP Number: H32
FEP Title: ***Waste-Induced Borehold Flow***

SCR-5.2.1.9.1 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*** *and* ***Natural Borehole Flow*** *through a future borehole that intersects a waste panel are accounted for in PA calculations.*

SCR-5.2.1.9.2 Summary of New Information

SCR-5.2.1.9.3 No new information has been identified for this FEP. This discussion for this FEP has been modified for editorial purposes.

SCR-5.2.1.9.4 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-5.2.1.9.4.1 *Future Human EPs*

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 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 Section 6.4.7.2). 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-5.2.1.9.4.2 *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 Section 6.4.7.2).

SCR-5.2.1.10 FEP Number: H34
FEP Title: ***Borehole-Induced Solution and Subsidence***

SCR-5.2.1.10.1 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-5.2.1.10.2 Summary of New Information

The original description and screening arguments for ***Borehole-Induced Solution and Subsidence*** around existing and future boreholes remain unchanged and valid. The change in hydraulic conductivity within the Culebra from ***Borehole-Induced Solution and Subsidence*** along the flow path will have no significant affect on the long-term performance of the disposal system. The effects have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The FEP description and screening arguments have been revised to include new information related to borehole-induced subsidence by recognizing new and developing sinks in the region.

SCR-5.2.1.10.3 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-5.2.1.10.3.1 *Historical, Current, and Near-Future Human EPs*

SCR-5.2.1.10.3.1.1 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 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 (TDS) 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 WIPP; the bottom of the drillhole is in the uppermost Castile Formation, 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. Wallace et al. (1982) analyzed natural processes of dissolution of the evaporites by water from the underlying Bell Canyon Formation. 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); 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 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 Formations), 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., in press). 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 (1000 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 (1986) considered the direction of natural fluid flow through boreholes in the vicinity of the WIPP. 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. Potentially, the direction of borehole fluid flow could 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, N17, and N18).

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 (1996c), the travel times should increase. If the transmissivity along the expected flow path decreased locally due to 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-5.2.1.10.3.2 *Future Human EPs*

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 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 Section 6.4.7.2). 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-5.2.1.10.3.2.1 *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 disturbed performance calculations by assuming that the borehole is eventually filled by such materials, which have the properties of a silty sand (see Section 6.4.7.2). However, these calculations assume that the borehole diameter does not increase with time. Under the conditions assumed in the SCR for the CCA for an E2 drilling event at 1,000 years, about 1,000 m^3 (35,316 ft^3) would be dissolved from the lower Rustler and upper Salado Formations. 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 disturbed performance. There is, however, no ***Borehole-Induced Solution and Subsidence*** under this circumstance, and therefore there is no effect on performance due to 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 (e.g., II-G-12, 3.12.3.3.). For dissolution at the top of the evaporite section (as with boreholes considered under HCN), the process can develop a localized area around the borehole in which the hydraulic parameters for the Culebra and other units are altered. 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-5.2.1.11 FEP Number: H35
FEP Title: ***Borehole Induced Mineralization***

SCR-5.2.1.11.1 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-5.2.1.11.2 Summary of New Information

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. Movement of compositionally different groundwater into the Culebra may lead to mineral precipitation, potentially changing porosity and permeability within the unit, and affecting contaminant transport. The potential effects of borehole-induced brine movement into the Culebra dolomite and mineral precipitation/ dissolution are discussed in FEPs H31 through H36. The original FEP description was slightly modified to include an evaluation of the effects of mineral precipitation on matrix diffusion.

SCR-5.2.1.11.3 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-5.2.1.11.3.1 *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 due to 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 and/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, due to mixing between brines and Culebra porewater, was addressed by Wang (1998). Wang showed that the volume of secondary minerals precipitated due to 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-5.2.1.11.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 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 Section 6.4.7.2). 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-5.2.1.11.4.1 *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 and H33). 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-5.2.1.12 FEP Number: H36
FEP Title: ***Borehole-Induced Geochemical Changes***

SCR-5.2.1.12.1 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-5.2.1.12.2 Summary of New Information

No new information has been identified. This FEP has been modified for editorial purposes.

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.

SCR-5.2.1.12.3.1 *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 for ***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 H24, 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-5.2.1.12.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 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 Section 6.4.7.2). 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 *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 Sections 6.4.3.6 and 6.4.6.2.1. Consistent with the discussion in H24, 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 H24, 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 H24, 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 HCN, and future potash mining are accounted for in PA calculations.

SCR-5.2.2.1.2 Summary of New Information

Changes in groundwater flow due to HCN, and future mining are included in PA calculations of groundwater flow and transport through the Culebra. The FEP description and screening argument have been modified slightly to reflect recent activities, but the screening decision is unchanged.

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 in the Salado is expected to continue in the vicinity of the WIPP (see 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 percent 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 undisturbed performance of the disposal system. The effects of any increased recharge that may be occurring are in effect included by using heads measured in 2000 (which should reflect that recharge) to calibrate Culebra transmissivity fields and calculate transport through those fields (Beauheim 2002). Changes (increases) in Culebra transmissivity are incorporated directly in the modeling of flow and transport in the Culebra (see Section 6.4.6.2.3).

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 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 40 CFR § 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 Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in 40 CFR § 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 40 CFR § 194.32(b), ***Changes in Groundwater Flow Due to Mining*** within the controlled area are accounted for in calculations of the disturbed performance of the disposal system (see 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 HCN potash mining have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Changes in geochemistry due to future mining have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.2.2.2 Summary of New Information

The only natural resource being mined underground currently near WIPP is potash in the McNutt, and it is the only mineral considered for future mining. Potash mining is also the only excavation activity currently taking place in the vicinity of the WIPP that could affect hydrogeological or geochemical conditions in the disposal system. It appears unlikely that underground mining will impact the site geochemistry during the time of passive institutional controls, and a conclusion of no near-term consequence is screened from future events as per 40 CFR § 194.25. Changes have been made to the screening argument. However, the screening decision remains the same.

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 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 (1982). D'Appolonia noted that attempts to solution mine sylvite in the Delaware Basin failed due to low ore grade, thinness of the ore beds, and problems with heating and pumping injection water. See discussion for potash mining FEP H13. Thus, ***Changes in Groundwater Flow 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 40 CFR § 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 Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in 40 CFR § 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 40 CFR § 194.32(b), changes in groundwater flow due to mining within the controlled area are accounted for in calculations of the disturbed performance of the disposal system (see Section 6.4.6.2.3). Other potential effects, such as ***Changes in Groundwater Flow 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 have 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

In the CCA, ***Solution Mining for Potash*** was not identified as a separate FEP, although all components of the solution mining process were accounted for in FEPs screening, albeit in a piecemeal fashion. For example, the drilling of the borehole necessary for solution injection or effluent recovery is addressed in FEP H8, ***Drilling For Other Resources,*** mainly because the physical and mechanical effects of the drilling activity do not vary based on the type of resource being sought, nor on the final intended use of the borehole; e.g., disposal well, injection well, solution mining, or oil and gas extraction. The removal of an ore as a result of solution mining is ultimately the same as if conventional mining processes had removed the ore. Potash mining using conventional methods is addressed in FEP H13, ***Conventional Underground Potash Mining***. The ultimate effect of such ore body removal is believed to be the eventual subsidence of the overlying units and the associated impact upon hydraulic conductivity. This has been demonstrated to have a negligible effect on performance of the WIPP, and is in fact accounted for in PA by EPA's requisite treatment of potash mining above the waste area.

Although the original FEP baseline considered different types of mineral and petroleum resource exploration/exploitation, it did not initially consider the possibility of brine mining (solution mining), even though this has occurred in the Delaware Basin. EPA noted this oversight in their March 1997 letter requesting additional information regarding the CCA (EPA 1997). In response to this request, the DOE submitted two memos (Hicks 1997a, 1997b) that addressed both ***Solution Mining for Potash*** and solution mining for brine. In EPA's TSD for §194.32, "Scope of Performance Assessments," EPA noted that these memos adequately supported the screening decisions presented in the CCA.

For CRA-2004, solution mining has been explicitly represented within the FEPs baseline through the additions of FEP H58***, Solution Mining for Potash*** and FEP H59, ***Solution Mining for Other Resources***. The reassessment of these EPs confirms that no significant developments have occurred since the CCA, and the arguments used by Hicks remain valid. The creation of these FEPs will aid in clarifying and separating the activities related to solution mining from conventional mining for potash as addressed in FEP H13.

SCR-5.2.2.3.3 Screening Argument

Currently, no ***Solution Mining for Potash*** occurs in the Carlsbad Potash District (CPD). The prospect of using solution-mining techniques for extracting potash has been identified in the region, but has not been implemented. A pilot plant for secondary solution mining of sylvite in the Clayton Basin, just north of the Delaware Basin was permitted, and concept planning took place during the mid-1990s and was noted by the EPA in their Response to Comments to the CCA (EPA 1998b). Five years later, this pilot project has yet to begin. Therefore, it is premature to consider this an operational solution mining activity. More importantly, the proposed site is outside the Delaware Basin.

The potash reserves evaluated by Griswold and Griswold (1999) and NMBMMR (1995) at WIPP are of economic importance in only two ore zones; the 4th and the 10th and 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. Due to the insolubility of langbeinite, sylvite is the only ore 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.

Communiqués with IMC Global (Heyn 1997, Prichard 2003), indicate that rock temperature is critical to the success of a solution-mining endeavor. IMC Global's solution mines in Michigan and Saskatchewan are at depths around 914 m (3,000 ft) or greater, at which rock temperatures are higher. The ore zones at WIPP are shallow, at depths of 457 to 549 m (1500 to 1800 ft), with fairly cool rock temperatures. David Prichard of IMC Global 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.

Typically, solution mining is used for potash:

- when deposits are at depths in excess of 914 m (3000 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; or

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

Douglas W. Heyn (chief chemist of IMC Kalium) provided written testimony to 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 was examined in detail by D'Appolonia (1982) and evaluated the possible effects of ***Solution Mining for Potash*** or other evaporite minerals. According to D'Appolonia (1982), and in agreement with 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. Solution mining of sylvite was unsuccessfully attempted in the past by the Potash Company of America and Continental Potash, both ore bodies currently owned by Mississippi Chemical. Failure of solution mining was attributed to low ore grade, thinness of the ore beds, and problems with heating and pumping injection water. Unavailability of water in the area would also impede implementation of this technique. For these reasons, solution mining is not currently used in the Carlsbad Potash District.

Serious technical and economic obstacles exist that render ***Solution Mining for Potash*** very unlikely in the vicinity of the WIPP. Expectedly, no operational example of this technology exists in the CPD; 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 1998b):

> …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.

No new data or information has become available that compromise, reduce, or invalidate the project's position on whether ***Solution Mining for Potash*** should be included in the PA calculations. Therefore, conventional mining activities will continue to be incorporated into the WIPP PA as directed by the EPA Compliance Application Guidance (CAG) (EPA 1996c). It remains to be seen if a viable potash solution mining project (or others like it) ever progress beyond the planning phase. Construction of a facility for solution mining is an expensive undertaking, and its use as a final recovery method implies that marginal (residual) ore quantities are available. Because the Carlsbad Potash District mines are in their mature stages (declining) of production, the significant financing required for a solution mining facility may not become available. Nonetheless, at the time of this FEP reassessment, this technology is not being employed. Therefore, a screening based on the future states assumption at 40 CFR § 194.25(a) is appropriate for this mining technique. Further, the proposed site is outside the Delaware Basin making it outside the scope of consideration.

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 Potash*** *has been eliminated from PA calculations on regulatory grounds. 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

See summary for H58.

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 Formations 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) as a drilling fluid until reaching the Bell Canyon Formation, 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 Formation, 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.

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 Vicinity of WIPP*

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 Delaware Basin Drilling Surveillance Program 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 15 brine wells within the Delaware basin, of which four are plugged and abandoned. This results in 11 currently active brine wells. Table SCR-3 provides information on these wells.

Table SCR-3. Delaware Basin Brine Well Status

County	Location	API No.	Well Name and No.	Operator	Status
Eddy	22S-26E-36	3001521842	City of Carlsbad #WS-1	Key Energy Services	Brine Well
Eddy	22S-27E-03	3001520331	Tracy #3	Ray Westall	Plugged Brine Well
Eddy	22S-27E-17	3001522574	Eugenie #WS-1	I & W Inc	Brine Well
Eddy	22S-27E-17	3001523031	Eugenie #WS-2	I & W Inc	Plugged Brine Well
Loving	Blk 29-03	4230110142	Lineberry Brine Station #1	Chance Properties	Brine Well
Loving	Blk 01-82	4230130680	Chapman Ford #BR1	Herricks & Son Co.	Plugged Brine Well
Loving	Blk 33-80	4230180318	Mentone Brine Station #1D	Basic Energy Services	Brine Well
Loving	Blk 29-28	4230180319	East Mentone Brine Station #1	Permian Brine Sales, Inc.	Plugged Brine Well

Table SCR-3. Delaware Basin Brine Well Status — Continued

County	Location	API No.	Well Name and No.	Operator	Status
Loving	Blk 01-83	4230180320	North Mentone #1	Chance Properties	Brine Well
Reeves	Blk 56-30	4238900408	Orla Brine Station #1D	Mesquite SWD Inc.	Brine Well
Reeves	Blk 04-08	4238920100	North Pecos Brine Station #WD-1	Chance Properties	Brine Well
Reeves	Blk 07-21	4238980476	Coyanosa Brine Station #1	Chance Properties	Brine Well
Ward	Blk 17-20	4247531742	Pyote Brine Station #WD-1	Chance Properties	Brine Well
Ward	Blk 01-13	4247534514	Quito West Unit #207	Seaboard Oil Co.	Brine Well
Ward	Blk 34-174	4247582265	Barstow Brine Station #1	Chance Properties	Brine Well

While these wells are within the Delaware Basin, none are within the vicinity of the WIPP. The nearest brine well to the WIPP is the Eugenie #WS-1, located within the city limits of Carlsbad, New Mexico. This well is approximately 48 km (30 mi) from the WIPP site.

SCR-5.2.2.4.5 Solution Mining for Other Minerals

Currently, there are no ongoing solution mining activities within the vicinity of 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 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 (Appendix DATA).

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 (NORM) 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. Gray (1991) quoted earlier analyses that show cavity stability is relatively high if the cavity has at least 15 m (50 ft) of overburden per million cubic feet of cavity volume (26.9 m per 50,000 m^3). There are two studies - discussed below - of the size of solution mining cavities in the Carlsbad region. These studies concern the Carlsbad Eugenie Brine Wells and the Carlsbad Brine Well and show that neither of these cavities are currently close to this critical ratio, but that subsidence in the future, given continued brine extraction, is a possibility.

Hickerson (1991) considered the potential for subsidence resulting from operation of the Carlsbad Eugenie Brine wells, where fresh water is injected into a salt section at a depth of 178 m (583 ft) and brine is recovered through a borehole at a depth of 179 m (587 ft). The boreholes are 100 m (327 ft) apart. Hickerson noted that the fresh water, being less dense than brine, tends to move upwards, causing the dissolution cavern to grow preferentially upwards. Thus, the dissolution cavern at the Carlsbad Eugenie Brine wells is approximately triangular in cross-section, being bounded by the top of the salt section and larger near the injection well. Hickerson estimated that brine production from 1979 until 1991 had created a cavern of about 9.6×10^4 m^3 (3.4×10^6 ft^3). The size of this cavern was estimated as 107 m (350 ft) by 47 m (153 ft) at the upper surface of the cavern with a depth of 39 m (127 ft).

Gray (1991) investigated the potential for collapse and subsidence at the Carlsbad Brine Well. Based on estimated production rates between 1976 and 1991, approximately 9.6×10^4 m^3 (3.4×10^6 ft^3) of salt has been dissolved at this site. The well depth is 216 m (710 ft) and thus there are about 64 m (210 ft) of overburden per million cubic feet of capacity (112 m of overburden per 50,000 m^3 of capacity).

Gray (1991) also estimated the time required for the cavity at the Carlsbad Brine Well to reach the critical ratio. At an average cavity growth rate of 6.4×10^3 m^3 per year (2.25×10^5 ft^3 per year), a further 50 years of operation would be required before cavity stability was reduced to levels of concern. A similar calculation for the Carlsbad Eugenie Brine well, based on an overburden of 140 m (460 ft) and an estimated average cavity growth rate of 7.9×10^3 m^3 per year (2.8×10^5 ft^3 per year), shows that a further 15 years of operation is required before the cavity reaches the critical ratio.

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 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 (OCD 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 (OCD 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.

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 historical, current, near-future, 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 historical explosions have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Changes in groundwater flow due to future explosions have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.3.1.2 Summary of New Information

No new information has been identified for this FEP.

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).

Also, as discussed in ***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 pre-existing 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 40 CFR § 194.32(a) relating to the scope of PAs limits the consideration of future human actions to mining and drilling. Also, consistent with 40 CFR § 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 Events and Processes

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

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 (DOE 2002). This FEP discussion has been updated with additional information about industrial land uses in the region.

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.

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 transmissivity fields developed for the CRA used water levels measured in 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 (DOE 2002). Therefore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), ***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 40 CFR § 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 Changes*** 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***

Future ***Surface Disruptions*** not affecting hydrogeologic or geologic conditions have been eliminated from PA calculations on regulatory grounds. 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 years 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 potash tailings ponds may be screened out on the basis of low consequence.

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

The effects of HCN **Surface Disruptions** *have been screened out on the basis of low consequence if they have no potential to affect the disposal system, or are implicitly included in PA calculations when they might affect the disposal system. The effects of future* **Surface Disruptions** *have been eliminated from PA calculations on regulatory grounds.*

SCR-5.3.1.2.2 Summary of New Information

The screening argument for ***Surface Disruptions*** has changed. Per the original screening decision, surface activities in the vicinity of the WIPP site have disrupted the surface, but most surface activities have no potential to affect the disposal system and are, therefore, screened out on the basis of low consequence. However, the effects of the activity capable of altering the disposal system (disposal of potash effluent) are included in our modeling of current conditions (i.e., heads) at and around the site. Therefore, the screening decision has been changed from SO-C to UP for HCN. Discussion regarding these anthropogenic effects is found in Section 2.2.1.4.2.2 of the CRA. There are no planned changes to land use in the vicinity of the WIPP in the near future, and future events that might disrupt the surface at the WIPP site are screened out on the basis of regulatory criteria.

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

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 transmissivity fields developed for the CRA used water levels measured in 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 (DOE 2002). Therefore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), ***Land Use Changes*** in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.2.5 Future Human EPs

The criterion in 40 CFR § 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 Changes*** need be considered in the vicinity of the WIPP, and they have been eliminated from PA calculations on regulatory grounds.

Future ***Surface Disruptions*** not affecting hydrogeologic or geologic conditions have been eliminated from PA calculations on regulatory grounds. 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 years 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 potash tailings ponds may be screened out on the basis of low consequence.

SCR-5.4 Surface Hydrological Events and Processes

SCR-5.4.1 Water Control and Use

SCR-5.4.1.1 FEP Number(s): H42, H43, and H44
FEP Title(s): ***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 has been identified related to these FEPs. Changes have been made for editorial purposes.

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 40 CFR § 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 has been identified related to this FEP. Changes have been made for editorial purposes.

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 H40 and H41.

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

As discussed in 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 194.32(c) and 194.54(b).

SCR-5.4.1.2.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 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 has been identified related to this FEP. Changes have been made for editorial purposes.

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 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.

SCR-5.4.1.3.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 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 Events and Processes

SCR-5.5.1 Anthropogenic Climate Change

SCR-5.5.1.1 FEP Number(s): H47, H48, and H49
FEP Title: ***Greenhouse Gas Effects*** (H47)
Acid Rain (H48)
Damage to the Ozone (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 has been identified related to this FEP. Changes have been made for editorial purposes.

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 Section 6.4.9. 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*** *(H48)*) or on a regional to global scale (***Greenhouse Gas Effects*** *(H47)* and ***Damage to the Ozone*** layer *(H49)*). 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 40 CFR § 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 Events and Processes

SCR-5.6.1 Marine Activities

SCR-5.6.1.1.1 FEP Number(s): H50, H51 & H52
FEP Title(s): ***Costal Water Use*** (H50)
Seawater Use (H51)
Estuarine Water (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 has been identified related to this FEP. Changes have been made for editorial purposes.

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 40 CFR § 194.32(c) and 40 CFR § 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 40 CFR § 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 Events and Processes

SCR-5.7.1 Agricultural Activities

SCR-5.7.1.1 FEP Number(s): H53, H54, and H55
FEP Title(s): ***Arable Farming*** (H53)

Ranching (H54)
Fish Farming (H55)

SCR-5.7.1.1.1 Screening Decision: SO-C (HCN)
SO-R (Future)

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 has been identified related to these FEPs.

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 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 40 CFR § 194.32(c) and 40 CFR § 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 40 CFR § 194.32(a) that limit the scope of consideration of future human activities in PAs to mining and drilling. Also, the criterion in 40 CFR § 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 has been identified for this FEP.

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 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 40 CFR § 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: NA (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 has been identified for this FEP. Changes have been made for editorial purposes.

SCR-5.7.2.2.3 Screening Argument

Human activities will be prevented from occurring within the controlled area in the near future. 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 40 CFR § 194.41(b), the DOE assumes no credit for active institutional controls for more than 100 years after disposal. Also, consistent with 40 CFR § 194.43(c), the DOE originally assumed in the CCA that passive institutional controls do not eliminate the likelihood of future human intrusion entirely. The provisions at 40 CFR 194.43(c) allow credit for passive institutional controls by reducing the likelihood of human intrusions for several hundred years. In DOE (1996a), the DOE took credit for these controls that include records retention by reducing the probability of intrusion for the first 600 years after active controls cease. EPA disallowed this credit during the original certification (EPA 1998a). DOE no longer takes credit for passive institutional controls in PA, effectively assuming that all public records and archives relating to the repository are lost 100 years after closure. Therefore, DOE continues to include the ***Loss of Records*** FEP within PA and does not include credit for passive institutional controls.

SCR-6.0 WASTE AND REPOSITORY-INDUCED FEPS

This section presents screening arguments and decisions for waste- and repository-induced FEPs. Of the original 108 waste- and repository-induced FEPs, 61 remain unchanged, 43 were updated with new information or were edited for clarity and completeness, three screening decisions were changed, and one FEP was deleted from the baseline by combining with other, more appropriate FEPs.

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

Representation of the repository within the PA has changed since the CCA; however, the screening argument and decision remain unchanged. **Disposal *Geometry*** is accounted for in PA calculations.

SCR-6.1.1.2 Screening Argument

Disposal *Geometry* is described in Chapter 3, Section 3.2 and is accounted for in the setup of PA calculations (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

The **Waste Inventory** *and* **Heterogeneity of Waste Forms** *are accounted for in PA calculations.*

SCR-6.1.2.1.2 Summary of New Information

No new information has been identified for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-6.1.2.1.3 Screening Argument

Waste characteristics, comprising the ***Waste Inventory*** and the ***Heterogeneity of Waste Forms***, are described in Chapter 4.0. The waste inventory is accounted for in PA calculations in deriving the dissolved actinide source term and gas generation rates (Sections 6.4.3.5 and 6.4.3.3). The distribution of contact-handled (CH) and remote-handled (RH) transuranic (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 (Section 6.4.7).

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 low consequence to the performance of the disposal system.*

SCR-6.1.3.1.2 Summary of New Information

The inventories of container materials (i.e., steel and plastic liners) are included in WIPP long-term PAs as input parameters of the gas generation model (Wang and Brush 1996). The ***Container Form*** has been eliminated from PA calculations on the basis of its beneficial effect on retarding radionuclide release. The PAs assume instantaneous container failure and waste dissolution according to the source-term model. The screening argument has been modified to incorporate additional information, although the screening decision has not changed.

SCR-6.1.3.1.3 Screening Argument

As in the CCA, the CRA calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 years (see Helton et al. 1998). For all undisturbed cases, at least 30 percent of the steels will remain uncorroded at the end of 10,000 years. In addition, it is assumed in both CCA and CRA-2004 calculations that there is no microbial degradation of plastic container materials in 75 percent of PA realizations (Wang and Brush 1996). All these undegraded container materials will (1) prevent the contact between brine and radionuclides; (2) decrease the rate and extent of radionuclide transport due to high tortuosity along the flow pathways and, as a result, increase opportunities for metallic 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. Both CCA and CRA assume instantaneous container failure and waste dissolution according to the source-term model. In 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 2003 update to the TWBIR Revision 3 (Appendix DATA, Attachment F) indicates that the density of steel in container materials currently reported by the sites has an average value of 170 kg/m^3. This is an increase over what was reported for the CCA (139 to 230 kg/m^3)(8.6 to 14.3 lb/ft^3). Therefore, the current inventory estimates indicate that there is a sufficient quantity of metallic iron to ensure reduction of radionuclides to lower and less soluble oxidation states. The 2003 update to the TWBIR Revision 3 (Appendix DATA, Attachment F) indicates that the density of plastic liners currently reported by the sites has an average value of 16 kg/m3. This is a decrease from 26 to 21 kg/m^3 (1.6 to 1.3 lb/ft^3) reported in the CCA.

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

No new information has been identified that relates to the screening of this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA; however, the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-6.1.3.2.3 Screening Argument

The ***Container Material Inventory*** is described in Chapter 4.0, and is accounted for in PA calculations through the estimation of gas generation rates (Section 6.4.3.3).

SCR-6.1.4 Seal Characteristics

SCR-6.1.4.1 FEP Number: W6 and W7
FEP Title: ***Seal Geometry*** (W6)
Seal Physical Properties (W7)

SCR-6.1.4.1.1 Screening Decision: UP

*The **Seal Geometry** and **Seal Physical Properties** are accounted for in PA calculations.*

SCR-6.1.4.1.2 Summary of New Information

No new information has been identified that relates to the screening of these FEPs. Since these FEP are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation are described in Section 6.4.4.

SCR-6.1.4.1.3 Screening Argument

Seal (shaft seals, panel closures, and drift closures) characteristics, including ***Seal Geometry*** and ***Seal Physical Properties***, are described in Section 3.3.2 and are accounted for in PA calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials (Section 6.4.4).

SCR-6.1.4.2 FEPs Number: W8
FEP Title: ***Seal Chemical Composition***

SCR-6.1.4.2.1 Screening Decision: SO-C Beneficial

*The **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

In the CCA, ***Seal Chemical Composition*** was screened out on the basis of predicted beneficial consequences, which are not credited in PA calculations. Recent publications 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, through sorption and sequestration of radionuclides. Ignoring adsorption simplifies the PA calculations, and is expected to produce somewhat more conservative results. However, because little or no upward flow is predicted to occur through the seals, the overall effect on PA results may not be significant.

The original FEP description has been modified slightly to include supporting evidence for the argument that chemical interactions between the cement seals and the brine will be of beneficial consequence to the performance of the disposal system.

SCR-6.1.4.2.3 Screening Argument

Seal (shaft seals, panel closures, and drift closures) characteristics, including ***Seal Geometry*** and ***Seal Physical Properties***, are described in CCA Chapter 3.0 and are accounted for in PA calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials. The effect of shaft ***Seal 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

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 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 recent 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.

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-6.1.5 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 related to this FEP has been identified. Changes have been made for editorial purposes.

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 CCA Appendix BACK with additional information contained in Appendix BARRIERS. The mechanical and thermal effects of backfill are discussed in W35 and W72 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

No new information related to this FEP has been identified. Changes have been made for editorial purposes.

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 Section 6.4.3.4. The mechanical and thermal effects of backfill are discussed in FEP W35 and FEP W72, 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 (Section 6.4.3).

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

The FEP screening argument has been modified to include reference to 40 CFR 194.42(d). Compliance with this requirement ensures that ***Post-Closure Monitoring*** is not detrimental to the performance of the repository. No changes have been proposed to the ***Post-Closure Monitoring*** program as presented in the CCA. The pre-closure monitoring program has not identified a condition relating to the act of monitoring that would be detrimental to the performance of the repository after closure (Annual Site Environmental Reports and Annual Compliance Monitoring Parameter Assessments). No changes have been made to the FEP description, screening argument, or screening decision.

SCR-6.1.6.1.3 Screening Argument

Post-Closure Monitoring is required by 40 CFR § 191.14(b) as an assurance requirement to "detect substantial and detrimental deviations from expected performance." The DOE has designed the monitoring program (see CCA Appendix MON) so that the monitoring methods employed are not detrimental to the performance of the disposal system (40 CFR 194.42(d)). Non-intrusive 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 Features, Events, and Processes

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 related to this FEP has been identified. No changes have been made.

SCR-6.2.1.1.3 Screening Argument

Radionuclide Decay and Ingrowth are accounted for in PA calculations (see Section 6.4.12.4).

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 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

WIPP transportation restrictions 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 watts 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 watts 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 2003 update to the TWBIR Revision 3 (Appendix DATA, Attachment F) indicates that the radionuclide inventory is lower than previously estimated for the CCA.

Thus, all CRA radioactive decay heating screening arguments are bounded by the previous CCA screening arguments.

SCR-6.2.1.3 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), fluid flow (W40 and W41), and geochemical processes (W44 through W75). 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 kW per acre. Transportation restrictions also require that the thermal power generated by waste in an RH-TRU container shall not exceed 300 watts (NRC 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 (1980 pp. 9-149 to 9-150). This study involved estimation of the thermal power of CH-TRU waste containers. The DOE (1980 pp. 9-149) analysis assumed the following:

- All CH-TRU waste drums and boxes contain the maximum permissible quantity of plutonium. The fissionable radionuclide content for CH-TRU waste containers was assumed to be no greater than 200 grams per 0.21 m^3 (7 ounces per 7.4 ft^3) drum and 350 grams per 1.8 m^3 (12.3 ounces per 63.6 ft^3) standard waste box (plutonium-239 fissile gram equivalents).

- The plutonium in CH-TRU waste containers is weapons grade material producing heat at 0.0024 watts per gram. Thus, the thermal power of a drum is approximately 0.5 watts and that of a box is approximately 0.8 watts.

- 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 Land Withdrawal Act [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 watts per square meter (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 (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 (1981) attributed this thermal load to RH-TRU waste, but the DOE (1980), more appropriately, attributed this thermal load to CH-TRU waste based on the assumptions listed above. 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 years after waste emplacement.

More recently, Sanchez and Trellue (1996) estimated the maximum thermal power of an RH-TRU waste container. The 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 1000 rem per hour. The following calculational steps were taken in the Sanchez and Trellue (1996) analysis:

- Calculate the absorbed dose rate for gamma radiation corresponding to the maximum surface dose equivalent rate of 1000 rem per hour. 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 millirem per hour, 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 per square centimeter per second.

- 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) 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 curie load of a RH-TRU container (including alpha and beta radiation) from the gamma load. The ratio of the total curie load to the gamma curie load was estimated through examination of the radionuclide inventory presented in CCA Appendix BIR. The gamma curie load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of total curie load to gamma curie load of RH-TRU waste was calculated to be 1.01.

- Calculate the thermal load of a RH-TRU container from the total curie load. The ratio of thermal load to curie load was estimated through examination of the radionuclide inventory presented in CCA Appendix BIR. The thermal load and the total curie load for each radionuclide listed in the WIPP inventory were summed. Based on these summed loads the ratio of thermal load to curie load of RH-TRU waste was calculated to be about 0.0037 watts per curie. 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 (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 percent 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 (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, analysis has shown that the average temperature increase in the WIPP repository, due to 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 watts (based on the maximum allowable surface dose equivalent for RH-TRU containers). Potential heat generation from nuclear criticality is discussed in W14 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. These FEPs have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

The previous FEPs screening arguments for the CCA used a bounding radioactivity heat load of 0.5 watts/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-gallon drum equivalents with a corresponding heat load of > 400 kW used for the CCA FEPs screening arguments. From 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 (TWBIR) is less than 100 kW. Thus, the CCA FEPs incorporate a factor of safety of at least four.

Since the 2003 update to the TWBIR Revision 3 (Appendix DATA, Attachment F) indicates that the radionuclide inventory is lower than that previously estimated for the CCA), all CRA-2004 radioactive decay heating screening arguments are bounded by the previous CCA screening arguments. Verification of the fact that heat loads for the CRA-2004 are less than those for the

CCA is provided in Djordjevic (2003). Djordjevic (2003) is a recalculation of the work of Sanchez and Trellue (1996) using radionuclide data from Appendix DATA, Attachment F.

SCR-6.2.1.4 FEPs Number: W14
FEPs Title: ***Nuclear Criticality: Heat***

SCR-6.2.1.4.1 Screening Decision: SO-P

Nuclear Criticality *has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.*

SCR-6.2.1.4.2 Summary of New Information

Heat generated via **Nuclear Criticality** was screened out based on the low probability that a criticality event would occur. The updated information for the WIPP disposal inventory of fissile material (Appendix DATA, Attachment F; Leigh 2003a) indicates that the expected WIPP-scale quantity is 43 percent lower than previously estimated in CCA TWBIR Rev 3. Thus, all CRA-2004 criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

SCR-6.2.1.4.3 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 generation of sizable precipitation zone); and (3) no credible mechanism exists for the concentrating fissile material during transport (the natural tendency is for transported to be dispersed). As discussed in Section 6.4.6.2 and CCA Appendix PA, Attachment MASS Section MASS.15, the dolomite porosity consists of intergranular porosity, vugs, microscopic fractures, and macroscopic fractures. As discussed in Section 6.4.5.2, porosity in the marker beds 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.

Screening arguments made in Rechard et al. (1996) are represented in greater detail in Rechard et al. (2000, 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. These previous arguments were based on radionuclide information from Revision 3 of the TWBIR (DOE 1996b). Of the 135 radionuclides presented in that TWBIR database, only 17 are possible contributors to fissile material. Table SCR-4 identifies these nuclides along with their conversion factors for specific activity and ^{239}Pu fissile gram equivalents (^{239}Pu fissile gram equivalent (FGE) per ANSI/ANS-18.5).

Radioactivity inventories for the fissile radionuclides used in the CCA and CRA-2004 are presented in Table SCR-5. Also shown in Table SCR-5 are the corresponding FGE inventories. Key amongst the information presented in this table is updated information for the WIPP disposal inventory of fissile material (Appendix DATA, Attachment F; Leigh 2003a) indicates that the expected WIPP-scale quantity is 43 percent lower than previously estimated in TWBIR Rev. 3. Thus, all CRA-2004 criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

SCR-6.2.2 Radiological Effects on Material Properties

SCR-6.2.2.1 FEP Number: W15, W16, and W17
FEP Title: ***Radiological Effects on Waste*** (W15)
Radiological Effects on Containers (W16)
Radiological Effects on Seals (W17)

SCR-6.2.2.1.1 Screening Decision: SO-C

Radiological Effects on the Properties of the Waste, Container, and Seals *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 FEPs screening argument has been updated by referencing new radiological waste data. The screening decision for these FEPs has not been affected or changed by these new data.

Table SCR-4. Properties of Fissile Radionuclides in the Actinide Series

Nuclide ID	Atomic Number	Atomic Number	Half-Life(1) (sec)	Mass Excess Value(2) (MeV)	Atomic Weight(3) (gm/mole)	Specific Activity(4) (Ci/gm)	Fissile Gram Equivalent Factor(5) (^{239}Pu)
^{233}U	92	233	5.0020E+12	36.914	233.040	9.6763E-03	1.00E+00
^{235}U	92	235	2.2210E+16	40.916	235.044	2.1611E-06	1.00E+00
^{237}Np	93	237	6.7530E+13	44.868	237.048	7.0476E-04	1.50E-02
^{238}Pu	94	238	2.7690E+09	46.160	238.050	1.7115E+01	1.13E-01
^{239}Pu	94	239	7.5940E+11	48.585	239.052	6.2146E-02	1.00E+00
^{240}Pu	94	240	2.0630E+11	50.122	240.054	2.2781E-01	2.25E-02
^{241}Pu	94	241	4.5440E+08	52.952	241.057	1.0300E+02	2.25E+00
^{242}Pu	94	242	1.2210E+13	54.714	242.059	3.8171E-03	7.50E-03
^{241}Am	95	241	1.3640E+10	52.931	241.057	3.4312E+00	1.87E-02
^{242m}Am	95	242	4.7970E+09	55.513	242.060	9.7159E+00	3.46E+01
^{243}Am	95	243	2.3290E+11	57.171	243.061	1.9929E-01	1.29E-02
^{243}Cm	96	243	8.9940E+08	57.177	243.061	5.1607E+01	5.00E+00
^{244}Cm	96	244	5.7150E+08	58.449	244.063	8.0883E+01	9.00E-02
^{245}Cm	96	245	2.6820E+11	60.998	245.065	1.7165E-01	1.50E+01
^{247}Cm	96	247	4.9230E+14	65.528	247.070	9.2752E-05	5.00E-01
^{249}Cf	98	249	1.1060E+10	69.718	249.075	4.0953E+00	4.50E+01
^{251}Cf	98	251	2.8340E+10	74.128	251.080	1.5855E+00	9.00E+01

1 Half-life data originally taken from ORIGEN2 decay library (Croff 1980). Data values presented in Ref. Sanchez 1996 (WIPP WPO# 037404).
2 Mass excess values originally taken from Nuclear Wallet Cards (Tuli 1985). Data values presented in Ref. Sanchez 1996 (WIPP WPO# 037404).
3 Atomic weight calculated from: ATWT (AMU) = AN (atomic mass number) – ME (mass difference in MeV, ME of C^{12} = 0) / 931.4943 (MeV per AMU, Parrington et al. 1996, pg. 58).
4 Specific Activity calculated from: A'= (Na ln(2))/(ATWT half-life), Ref. Turner 1992, pg. 64 and A (Ci/gm) = A'(Bq/gm) / 3.7E+10 (Bq/Ci), Turner 1992, pg. 43, where Na = Avogadro's number = 6.02213676E+23 (atom/mole, Parrington, pg.59).
5 FGE (^{239}Pu based) data values from NuPac 1989 (TRUPACT-II SAR/Table 10.1/pg. 1.3.7-51 (data originally from Ref. ANSI/ANS-8.15 1981).

Table SCR-5. Fissile Equivalents of Radionuclides in the Actinide Series

Nuclide ID	Radioactivity Inventory(1) (Ci)				Nuclide Fissile Mass(2) (FGE-^{239}Pu)			
	TWBIR 3 (1995)	TWBIR 3 (2033)	2003 UpDate (2002)	2003 UpDate (2033)	TWBIR 3 (1995)	TWBIR 3 (2033)	2003 UpDate (2002)	2003 UpDate (2033)
^{233}U	1.95E+03	1.95E+03	1.27E+03	1.27E+03	2.02E+05	2.02E+05	1.31E+05	1.32E+05
^{235}U	1.74E+01	1.75E+01	2.26E+00	2.28E+00	8.05E+06	8.10E+06	1.05E+06	1.06E+06
^{237}Np	5.90E+01	6.49E+01	5.46E+00	1.01E+01	1.26E+03	1.38E+03	1.16E+02	2.14E+02
^{238}Pu	2.61E+06	1.94E+06	1.61E+06	1.25E+06	1.72E+04	1.28E+04	1.07E+04	8.27E+03
^{239}Pu	7.96E+05	7.95E+05	6.66E+05	6.64E+05	1.28E+07	1.28E+07	1.07E+07	1.07E+07
^{240}Pu	2.15E+05	2.14E+05	1.09E+05	1.09E+05	2.12E+04	2.11E+04	1.07E+04	1.07E+04
^{241}Pu	2.45E+06	3.94E+05	2.51E+06	5.38E+05	5.35E+04	8.61E+03	5.49E+04	1.18E+04

Table SCR-5. Fissile Equivalents of Radionuclides in the Actinide Series — Continued

Nuclide ID	Radioactivity Inventory[(1)] (Ci)				Nuclide Fissile Mass[(2)] (FGE-^{239}Pu)			
	TWBIR 3 (1995)	TWBIR 3 (2033)	2003 UpDate (2002)	2003 UpDate (2033)	TWBIR 3 (1995)	TWBIR 3 (2033)	2003 UpDate (2002)	2003 UpDate (2033)
^{242}Pu	1.17E+03	1.17E+03	2.71E+01	2.71E+01	2.30E+03	2.30E+03	5.33E+01	5.32E+01
^{241}Am	4.48E+05	4.88E+05	4.15E+05	4.58E+05	2.44E+03	2.66E+03	2.26E+03	2.50E+03
^{242m}Am	1.75E+00	1.47E+00	2.44E-01	2.11E-01	6.23E+00	5.23E+00	8.67E-01	7.50E-01
^{243}Am	3.26E+01	3.25E+01	2.18E+01	2.17E+01	2.11E+00	2.10E+00	1.41E+00	1.41E+00
^{243}Cm	5.23E+01	2.07E+01	8.87E-01	4.07E-01	5.07E+00	2.01E+00	8.59E-02	3.94E-02
^{244}Cm	3.18E+04	7.44E+03	1.18E+04	2.51E+03	3.54E+01	8.28E+00	1.32E+01	2.79E+00
^{245}Cm	1.15E-02	1.15E-02	1.90E-02	1.92E-02	1.00E+00	1.00E+00	1.66E+00	1.68E+00
^{247}Cm	3.21E-09	9.51E-09	9.44E+00	9.45E+00	1.73E-05	5.13E-05	5.09E+04	5.09E+04
^{249}Cf	6.87E-02	6.38E-02	7.72E-02	7.24E-02	7.55E-01	7.01E-01	8.48E-01	7.96E-01
^{251}Cf	3.78E-03	3.67E-03	5.23E-04	5.10E-04	2.15E-01	2.08E-01	2.97E-02	2.90E-02
				Σ	2.11E+07	2.12E+07	1.20E+07	1.20E+07

[1] TWBIR Rev. 3 data values originally from DOE 1996b. Data values presented in Sanchez 1997, pp. 27-30. TWBIR 2003 Update 2002 (beginning of calendar year) data from Appendix DATA, Attachment F. TWBIR 2002 Update 2033 (end of calendar year) data from Leigh 2003a.

[2] ^{239}Pu Fissile Gram Equivalents calculated from: FGE(^{239}Pu) = Inventory (Ci) * FGE Factor (from Table 1) / A'(Ci/gm, from Table 1).

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 new *inventory* data, the total radionuclide inventory decreased from 7.44×10^6 (DOE 1996b) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Such a small decrease will not change the original screening argument. In addition, PA calculations assume instantaneous container failure and waste dissolution according to the source-term model (see Sections 6.4.3.4, 6.4.3.5, and 6.4.3.6. Therefore, ***Radiological Effects on the Properties of the Waste, Container, and Seals*** 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 Features, Events, and Processes

SCR-6.3.1 Excavation-Induced Changes

SCR-6.3.1.1 FEP Number: W18 and W19
FEP Title: ***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 (*DRZ*) *and changes in stress are accounted for in PA calculations.*

SCR-6.3.1.1.2 Summary of New Information

No new information has been identified relating to these two FEPs. No changes have been made since the CRA.

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 Section 3.3.1.5. This 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, MB139, and, possibly, MB138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and marker beds 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 (Section 6.4.5.3).

The DRZ around repository shafts could provide pathways for flow from the repository to hydraulically conductive units above the repository horizon. The effectiveness of long-term shaft seals is dependent upon the seals providing sufficient backstress for salt creep to heal the DRZ around them, so that connected flow paths out of the repository horizon will cease to exist. These factors are considered in the current seal design.

SCR-6.3.1.2 FEP Number: W20 and W21
FEP Title: ***Salt Creep*** (W20)
Change in the Stress Field (W21)

SCR-6.3.1.2.1 Screening Decision: UP

Salt Creep *in the Salado and resultant* **Changes in the Stress Field** *are accounted for in PA calculations.*

SCR-6.3.1.2.2 Summary of New Information

No new information has been identified relating to these two FEPs. No changes have been made since CRA-2004.

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 (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 seals to achieve a low permeability under stresses induced by salt creep. Seal performance is discussed further in FEPs W36 and W37.

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 falls on flow paths are accounted for in PA calculations.

SCR-6.3.1.3.2 Summary of New Information

No new information has been identified relating to this FEP. No changes have been made since the CRA.

SCR-6.3.1.3.3 Screening Argument

Instability of the DRZ could to lead to localized ***Roof Falls*** in the first few hundred years. 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 leading to 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 the 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 Number(s): W23 and W24
FEP Title(s): ***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 years.*

SCR-6.3.1.4.2 Summary of New Information

The DOE acknowledges that proximal ***Roof Falls*** (see W22, Appendix SCR, Section SCR.2.3.3) will occur and minor subsidence of stratigraphic units overlying the Salado at WIPP could occur. Subsidence of geologic formations overlying the WIPP due to ***Salt Creep*** is shown to be only modestly perturbed and the consequence is captured by the uncertainty employed in the PA. ***Roof Falls*** and large-scale ***Subsidence*** have therefore been screened out of the PA calculations based upon low consequence. The potential effects of ***Roof Falls*** on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ. Continuous survey data, reported annually, reaffirm that ***Subsidence*** is minimal and near the accuracy of the survey itself (COMPs, annual reports). Changes for clarity and editorial purposes have been made to the screening argument.

SCR-6.3.1.4.3 Screening Argument

Instability of the DRZ could to lead to localized ***Roof Falls*** in the first few hundred years. 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 leading to 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 the PA assumed that a higher permeability zone remained for the long term. The 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 to 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 Potash Member (hereafter called the McNutt). At the WIPP site, the base of the

McNutt is about 150 m (490 ft) above the repository horizon. Also, the WIPP rock extraction ratio in the waste disposal region will be about 22 percent, as compared to 65 percent 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 landsurface. 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 percent 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 percent. 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 hydraulic conductivity varies spatially over approximately four orders of magnitude, from 1×10^{-8} m (3.2×10^{-8} ft) per second (0.4 m (1.3 ft) per year) to 1×10^{-5} m (3.2×10^{-5} ft) per second (Appendix PA, Attachment TFIELD). 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; EPA 1996b).

The equivalent porous medium hydraulic conductivity, *K* (meters per second), of a system of parallel fractures can be calculated assuming the cubic law for fluid flow (Witherspoon et al. 1980):

$$K = \frac{w^3 \rho g N}{12 \mu 2}, \tag{10}$$

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 (9.79 m (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 year (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 PA, Attachment TFIELD).

The amount of opening of each fracture as a result of subsidence-induced tensile vertical strain, ε, (assuming rigid rock) is *Dε/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 year (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 the PA calculations, multiple realizations of the Culebra transmissivity field are generated as a means of accounting for spatial variability and uncertainty (Appendix TFIELD). A change in hydraulic conductivity of one order of magnitude through vertical strain is within the range of uncertainty incorporated in the Culebra transmissivity field 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 year (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 Number: W25 and W26
FEP Title: ***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** *flow are accounted for in PA calculations.*

SCR-6.3.2.1.2 Summary of New Information

No new information has been identified relating to these FEPs. No changes have been made.

SCR-6.3.2.1.3 Screening Argument

The mechanical effects of gas generation, including the slowing of creep closure of the repository due to gas ***Pressurization***, and the fracturing of interbeds in the Salado through ***Disruption Due to Gas Effects*** are accounted for in PA calculations (Sections 6.4.5.2 and 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 has been identified related to this FEP. Only editorial changes have been made to this FEP.

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, 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**,** Attachment PCS) indicates that the most explosive mixture of hydrogen, methane, and oxygen will be present in the void space approximately 20 years 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 years.*

SCR-6.3.3.2.2 Summary of New Information

Editorial changes have been made for clarity as well as separating the two FEPs within the original SCR text into discrete arguments. Additional information is referenced to support the conclusions.

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 years. For a ***Nuclear Explosions*** 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. Radioactivity inventories for the fissile radionuclides used in DOE (1996a) and CRA-2004 are presented in Table SCR-6. The updated information for the WIPP disposal inventory of fissile material (Appendix DATA, Attachment F; Leigh 2003a) indicates that the expected WIPP-scale quantity is 43 percent lower than previously estimated in TWBIR Rev. 3 (DOE 1996b). Thus, all CRA-2004 criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

SCR-6.3.4 Thermal Effects

SCR-6.3.4.1 FEP Number: W29, W30, W31, W72, and W73
FEP Title: ***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 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

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. ***Concrete Hydration*** in the seals is a significant source of heat, but it is relatively short-lived. Energy released by the 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. Elevated temperatures will persist for a short period of time, perhaps a few years or a few decades. The thermal stresses from these temperatures and the temperatures in the concrete itself have been calculated to be below the design compressive strength for the concrete. Thus, thermal stresses should not degrade the long-term performance of the seals. In general, the various sources of heat do not appear to be great enough to jeopardize the performance of the disposal system.

The original FEP descriptions have been changed slightly to include the effects of water release during carbonation of the backfill, and the effects of formation of metastable hydrated carbonate minerals.

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 marker beds, 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. Potentially***, Thermal Effects on Material Properties*** (such as permeability and porosity) could affect the behavior of the repository.

Radioactive decay (W13), ***Nuclear Criticality*** (W14), and ***Exothermic Reactions*** (W72 and W73) are three possible sources of heat in the WIPP repository. According to the new inventory data, the total radionuclide inventory decreases increases from 7.44 × 106 (DOE 1996b) to 6.66 × 106 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Such a small change will not result in a significant deviation from the possible temperature rise predicted in the CCA. Exothermic reactions in the WIPP repository include MgO hydration, MgO carbonation, Al corrosion, and ***Cement Hydration*** (Bennett et al. 1996). 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. For these reactions, the calculated temperature rises need to be updated for the changes in both brine inflow rate and waste inventory. According to the CRA-2004 PA calculations, the average brine inflow rate upon a human intrusion is 156 m^3/year (204 yd^3/year), with a maximum value of 332 m^3/year (434 yd^3/year). In the CCA, the maximum brine inflow rate was assumed to be 200 m^3/year (261 yd^3/year). With the new rate of 332 m^3/year (434 yd^3/year), it is estimated that the temperature rise by each exothermic reaction is increased by 29 percent if the quantity of reactant remains the same. Changes in the amounts of reactants are tabulated in Table SCR-6.

Table SCR-6. Changes in Inventory Quantities from the CCA to the CRA

Inventory	CCA	CRA	Change
MgO (tons)	85,600[1]	72,760 (because of the elimination of mini-sacks)[a]	–15%
Cellulosics (tons)	5,940[2]	8,120[3]	37%
Plastics (tons)	3,740[2]	8,120[3]	117%
Rubber (tons)	1,100[2]	1,960[3]	78%
Aluminum alloys (tons)	1,980[2]	1,960[3]	–1%
Cement (tons)	8,540[2]	9,971[5]	17%

[1] U.S. DOE (2001)
[2] U.S. DOE (1996b). Only CH wastes are considered. Total volume of CH wastes is 1.1×10^5 m^3. This is not scaled to WIPP disposal volume.
[3] Appendix DATA, Attachment F. Only CH wastes are considered. Total volume of CH waste is 1.4×10^5 m^3. This is not scaled to WIPP disposal volume.
[4] This estimate is derived from data in Leigh (2003b) includes both reacted and unreacted cement. (1.2e7 kg x 1.4e5/168485 /1000 kg/ton = 9971 tons cement)

Similarly, MgO carbonation, which consumes ***Carbon Dioxide***, is limited by ***Carbon Dioxide*** generation from microbial degradation. Given a biodegradation rate constant, the total CO_2 generated per year is proportional to the total quantity of biodegradable materials in the repository. The inventory of biodegradable materials has been changed from 13,398 (5,940 + 1.7 × 3,740 + 1,100)[1] tons to 23,884 (8,120 + 1.7 × 8,120 + 1,960)[1] tons of equivalent cellulosics (Wang and Brush 1996a and 1996b). This increase in biodegradeable materials corresponds to a proportional increase in CO_2 generation. 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-7.

Temperature rises (^{o}C) by exothermic reactions are revised as follows:

Table SCR-7. CCA and CRA Exothermic Temperature Rises

Reactant	CCA[1]	CRA1
MgO hydration	< 4.5	< 4.7
Backfill Carbonation	< 0.6	< 0.7
Microbial degradation	< 0.8	< 1.4
Aluminum corrosion	< 6.0	< 6.8
Cement hydration	< 2.0	< 2.5

[1] All values are shown in degrees Celsius

[1] The 1.7 molar conversion rate for plastic is based on analyses presented in Wang and Brush (1996a and ***1996***b).

For the CCA conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) 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-2004 are still less than 10^{o}C (18°F) (as shown in Table SCR-7). 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.

SCR-6.3.5 Mechanical Effects on Material Properties

SCR-6.3.5.1 FEP Number: W32, W36, W37 and W39
FEP Title: ***Consolidation of Waste*** (W32)
Consolidation of Seals (W36)
Mechanical Degradation of Seals (W37)
Underground Boreholes (W39)

SCR-6.3.5.1.1 Screening Decision: UP

Consolidation of Waste *is accounted for in PA calculations.* ***Consolidation of Seals*** *and* ***Mechanical Degradation of Seals*** *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

No new information has been identified for these FEPs; however, because they are accounted for (UP) in PA, the implementation may differ from that used the CCA**)**. No information has been identified that would change the screening decision of UP. Changes in implementation (if any) are described in Chapter 6.0.

SCR-6.3.6.1.3 Screening Argument

Consolidation of Waste is accounted for in PA calculations in the modeling of creep closure of the disposal room (Section 6.4.3.1).

Mechanical Degradation of Seals and ***Consolidation of Seals*** are accounted for in PA calculations through the permeability range assumed for the seal system (Section 6.4.4).

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

Movement of Containers has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The FEP description has been updated to reflect new waste inventory data (waste density).

SCR-6.3.5.2.3 Screening Argument

Movement of Waste Containers placed in salt may occur as a result 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, aluminum 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 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 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 DOE (1996a) concerning container movement.

The first factor is changes in density of the waste form. For the most part, waste density will remain as assumed in the CCA. According to new *inventory* data (Appendix DATA, Attachment F), the revised waste density has changed by at most 10 percent (lower). Some future waste streams may however be more highly compacted, perhaps having a density roughly three times greater than that assumed in the CCA. In calculations of container movement, Dawson and Tillerson (1978, p. 22) varied container density by nearly a factor of three (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 backfills) relative to its heat production. Radioactive decay, ***Nuclear Criticality***, and exothermic reactions are three possible sources of heat in the WIPP repository. According to the new inventory data, the total radionuclide inventory decreases from 7.44×10^6 (CCA) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Such a small change will not result in a significant deviation from the possible temperature rise predicted in the CCA. As shown in Section SCR.6.3.4 (FEPs W72 and W73), temperature rises from exothermic reactions are quite small (see Table SCR-7). Note that the revised maximum temperature rises by exothermic reactions are still less than 10^{o}C (18°F).

Based on the small differences between the temperature and density assumed in the CCA compared to those determined using *new inventory* data (Appendix DATA, Attachment F), 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. Also, 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-6.3.6.3.1 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 has been identified relating to this FEP. Editorial changes have been made to the FEP screening argument.

SCR-6.3.5.3.3 Screening Argument

Container Integrity is required only for waste transportation. As in the CCA, the CRA-2004 calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 years (see Helton et al. 1998). For all undisturbed cases, at least 30 percent of the steels will remain uncorroded at the end of 10,000 years. In addition, it is assumed in both CCA and CRA-2004 calculations that there is no microbial degradation of plastic container materials in 75 percent 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 due to 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, the ***Container Integrity*** can be eliminated on the basis of its beneficial effect on retarding radionuclide transport. Both ***CCA*** and CRA-2004 assume 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

In 2001, MgO mini-sacks were eliminated from the repository, which decreases the backfill to waste volume ratio (EPA 2001). Although the backfill will provide additional resistance to creep closure, most of the resistance will be provided by the waste. Therefore, inclusion of backfill would not significantly reduce the total ***Subsidence*** in the waste rooms, and screening based on low consequence is appropriate. The screening argument has been updated to reflect the elimination of minisacks.

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). Since 2001, DOE has eliminated MgO mini sacks from the repository reducing the total inventory from 85,600 short tons to 74,000 short tons, which further reduces the potential backfill volume (EPA 2001). 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-6.3.5.5 FEP Number: W38
FEP Title: ***Investigation Boreholes***

SCR-6.3.5.5.1 Screening Decision: NA

SCR-6.3.5.5.2 Summary of New Information

The effects of ***Investigation Boreholes*** (whether sealed or not) that penetrate the disposal horizon but do not intersect the waste panels are encompassed by the arguments made in ***Natural***

Borehole Fluid Flow (H31) and ***Flow Through Undetected Boreholes*** (H33). FEP W38 has been deleted from the FEPs baseline because it is redundant. The effects of drillholes drilled from the underground are accounted for in PA by assumptions about the permeability of the DRZ. ***Natural Borehole Fluid Flow*** (H31) and ***Flow Through Undetected Boreholes*** (H33) encompass the effects of W38. Therefore, W38, ***Investigation Boreholes,*** has been deleted from the FEPs Baseline.

SCR-6.4 Subsurface Hydrological and Fluid Dynamic Features, Events, and Processes

SCR-6.4.1 Repository-Induced Flow

SCR-6.4.1.1 FEP Number: W40 and W41
FEP Title: ***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

No new information has been identified related to these FEPs. No changes have been made to the screening decisions or screening arguments.

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 (Section 6.4.3.2).

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 due to drilling intrusion are also influenced by brine saturations and therefore by ***Wicking***. Capillary rise is therefore accounted for in PA calculations (Section 6.4.3.2).

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 in the repository and Salado due to gas production is accounted for in PA calculations.

SCR-6.4.2.1.2 Summary of New Information

No new information has been identified related to this FEP. Only editorial changes have been made.

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). 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 (Section 6.4.3.2).

SCR-6.4.3 Thermal Effects

SCR-6.4.3.1 <u>FEP Number: W43</u>
<u>FEP Title: ***Convection***</u>

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

No new information has been identified relative to the screening of this FEP. The FEP description has been updated and modified for editorial purposes.

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. Potentially, thermal gradients in the disposal rooms could 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.

Nuclear Criticality (W13), ***Radioactive Decay*** (W14), and ***Exothermic Reactions*** (W72) are three possible sources of heat in the WIPP repository.

The characteristic velocity, Vi, for convective flow of fluid component I in an unsaturated porous medium is given by (from Hicks 1996);

$$V_i \approx -\frac{k_i}{\mu_i}(\alpha_i \rho_{i0} g \Delta T), \tag{11}$$

where α_i (per degree) is the coefficient of expansion of the i^{th} component, k_i is the intrinsic permeability (square meters), μ_i is the fluid viscosity (pascal second), ρ_{i0} (kilograms per cubic meter) is the fluid density at a reference point, g is the acceleration of 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 year (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 year (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 year (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 year (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 of fluid flow resulting from gas generation. In addition, the buoyancy forces generated by smaller temperature contrasts in the DRZ, resulting from backfill and ***Concrete Hydration*** and ***Radioactive Decay***, will be short-lived and insignificant compared to the other driving forces for fluid flow. The short-term concrete seals will be designed to function as barriers to fluid flow for at least 100 years after emplacement, and seal permeability will be minimized (Wakeley et al. 1995). Thus, temperature increases associated with ***Concrete Hydration*** will not result in significant buoyancy driven fluid flow through the concrete seal system. In summary, temperature changes in the disposal system will not cause significant thermal ***cConvection***. Furthermore, the induced temperature gradients will be insufficient to generate water vapor and drive significant moisture migration.

Temperature effects on fluid viscosity would be most significant in the DRZ surrounding the hydrating concrete seals (where temperatures of approximately 38°C (100°F) are expected). The viscosity of pure water decreases by about 19 percent 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, 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 seven percent (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 seven percent. 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 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 affect the long-term performance of the disposal system significantly.

For the CCA conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) 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-2004 are still less than 10 °C (18°F) (as shown in Table SCR-7). Such small temperature changes cannot affect material properties.

In summary, temperature changes in the disposal system will not cause significant thermally-induced two-phase flow. Thermal ***cConvection*** 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 Features, Events, and Processes

SCR-6.5.1 Gas Generation

SCR-6.5.1.1 FEP Number: 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 and Biofilm Formation on Microbial Gas Generation*** *are incorporated in the gas generation rates used.*

SCR-6.5.1.1.2 Summary of New Information

No new information has been identified related to the screening of these FEPs. Editorial changes have been made to the screening argument. The screening decision remains unchanged.

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, but also nitrogen oxide, nitrogen, hydrogen sulfide, hydrogen, and methane. 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 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. Numerical analysis suggests that the average temperature increase in the WIPP repository caused by radioactive decay of the emplaced CH- and RH-TRU waste is likely to be less than 3°C (5.4°F) (FEP W13).

Temperature increases resulting from ***Exothermic Reactions*** are discussed in FEPs W72 and W73. 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, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5.3°C (9.5°F), resulting from ***Brine Inflow*** following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years 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 reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature rise of about 7.9°C (14.2°F) (see W72). These calculated maximum heat generation rates resulting from aluminum 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 10°C (18°F) represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

Relatively few data exist on the ***Effects of Temperature on Microbial Gas Generation*** under expected WIPP conditions. 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). Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by 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 reference temperature of 30°C (86°F), based on the average temperature expected in the repository. Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Section 6.4.3.3. 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 (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 (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 (1994) support the gas generation rate data reported by 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 Section 6.4.3.3. 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 FEP W87.

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

The FEP screening argument has been updated, however the screening decision has not changed.

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 (2150 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 methane with minor amounts of nitrogen oxide, nitrogen, and hydrogen sulfide. The accumulation of these gaseous species will contribute 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 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*** (W44) 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 suggest (for example, Kato et al. 1994, p. 94) 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 new radionuclide inventory, 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 WIPP PA calculations. According to the new *inventory* data, the total radionuclide inventory decreases from 7.44×10^6 (DOE 1996b) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease Such a small change 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 Number: W49 and W51
FEP Title: ***Gasses 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

No new information has been identified related to these FEPs. They have been modified only from an editorial perspective, and have not changed since the CCA.

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 (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 (1993) support the gas generation rate data reported by 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 Section 6.4.3.3. 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

The original screening argument confused ***Galvanic Coupling*** internal and external to the repository (see W95). As such, the original screening decision for ***Galvanic Coupling*** was screened out on probability however, it is more appropriate to screen this FEP on consequence. The screening decision has therefore been changes to SO-C and a clear distinction between which FEP considers internal and external coupling was included in the FEP discussions.

Consideration ***Galvanic Coupling*** (W50), is restricted to consideration of effects between or among materials within the repository. ***Galvanic Coupling*** with materials outside the repository is considered in ***Galvanic Coupling*** (W95).

Galvanic Coupling (within the repository) is unlikely to occur on a large scale. On a very small scale, ***Galvanic Coupling*** could occur whenever two dissimilar metals are in contact and a conducting medium is present. However, the resulting corrosion would cause the same effects as the other corrosion processes already included in the assessments. Thus, ***Galvanic Coupling***, as a distinct corrosion mechanism, would have negligible effects on repository performance.

Galvanic Coupling has been screened out on the basis of low consequence. No new information has become available that affects the screening argument; the FEP screening argument and screening decision remain unchanged.

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 (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 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 is available relative to this FEP and screening decision. The screening argument has been modified for editorial purposes.

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

$$H_2O = H_2 + \frac{1}{2} O_2 \qquad (12)$$

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. (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 percent that of hydrogen.

An estimate of the potential rate of gas generation due to 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}Puconcentrations in the disposal room brines are controlled by solubility equilibria.

- All of the dissolved plutonium is ^{239}Pu.

R_{RAD} is then given by

$$R_{RAD} = \frac{Y_g C_{Pu} SA_{Pu} \overline{E}_\alpha V_B}{N_D N_A} \tag{13}$$

$$R_{RAD} = \frac{\left(\frac{1.5 \text{ molecule gas}}{\text{molecule } H_2O}\right)\left(3.15\times10^{7}\,\frac{\text{sec}}{\text{yr}}\right)\left(3\times10^{-4}\,\frac{\text{mol}}{\text{L}}\right)\left(5.42\times10^{11}\,\frac{\text{Bq}}{\text{mol}}\right)\left(5.15\times10^{6}\,\frac{\text{eV}}{\text{dis}}\right)\left(\frac{0.015\ H_2O}{100\ \text{eV}}\right)\left(4.36\times10^{8}\,\text{L}\right)}{\left(8\times10^{5}\ \text{drums}\right)\left(6.022\times10^{23}\,\frac{\text{molecules}}{\text{mole}}\right)} \tag{14}$$

R	=	rate of gas production (moles per drum per year)
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 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 (liters)
N_D	=	number of CH 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 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 due to the ***Radiolysis of Brine*** of 0.6 moles per drum per year.

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} liters (1.8×10^{4} gallons) per year.

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} liters (3.4×10^{5} and 1.0×10^{7} gallons) per year; anoxic corrosion of steels has the potential to yield up to 6.3×10^{5} liters (1.6×10^{5} gallons) per year.

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. (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 complementary cumulative distribution functions (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. (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. (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. In addition, the screening argument has been modified by the inclusion of gas generation information from the WIPP transportation program.

SCR-6.5.1.7.3 Screening Argument

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 (1979, p. 4) are given in terms of most probable ranges, using units of moles per year 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 year per drum is reported for gas generation due to radiolysis of cellulosic material (Molecke 1979, p. 4). As a comparison, a most probable range of 0.0 to 5.5 moles per year per drum is reported for gas generation by bacterial degradation of waste.

The data reported by 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* data, the total radionuclide inventory decreases from 7.44×10^6 (DOE 1996b) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Interestingly, the radionuclide inventory in the CH-TRU waste, which accounts for the most volume of WIPP wastes, decreases from 6.42×10^6 (DOE 1996b) to 5.33×10^6 curies (Appendix DATA, Attachment F). Such a small change will not affect radiolytic gas generation. However, the new inventory data indicates a 7 percent increase in the density of cellulose in waste materials (Appendix DATA, Attachment F). Because the additional cellulose component is mainly derived from the Advanced Mixed Waste Treatment Plant (AMWTP) wastes, which have relatively low radioactivity, the increase in total cellulose quantity will not significantly affect the prediction of total radiolytic gas generation.

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 five percent over 60 days (DOE 2000). Thus, the maximum rate allowed for transportation is 0.201 m^3 per drum × five percent × 1000 L/m^3 per 60 days × 365 days per year = 61 L per drum per year, smaller than the maximum microbial gas generation rate. Note that this estimate is very conservative and the actual rates are even smaller. It is a 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 (2.48 million curies of TRU isotopes) is less than previously estimated in TWBIR Rev 3 (DOE 1996b). Thus, the ***Helium Gas Production*** argument for CRA-2004 is conservatively bounded by the previous CCA screening argument. The FEP screening argument and screening decision remain unchanged except for editorial changes.

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 α-particles generated during radioactive decay. The α-particles are converted to helium gas by the following reaction:

$$^{4}He^{2+} + 2e^{-} \rightarrow He(g) \qquad (15)$$

For the screening argument used in the CCA, the inventory (I) that may be emplaced in the repository is approximately 4.07 million curies or 1.5×10^{17} becquerels (see CCA Appendix BIR). Assuming that the inventory continues to yield α-particles at this rate throughout the 10,000-year regulatory period the maximum rate of helium gas produced (R_{He}) may be calculated from

$$R_{He} = \frac{1\left(\frac{1 \text{ He atom}}{\alpha - \text{decay}}\right)}{N_A} \qquad (16)$$

R_{He} is the rate of ***Helium Gas Production*** in the repository (mole per second)

I is the waste inventory, 1.5×10^{17} becquerels, assuming that 1 becquerel is equal to 1 α-decay per second, and N_A is Avogadro 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 alpha-emitting inventory of 4.07 million curies. Assuming ideal gas behavior and repository conditions of 30°C (86°F) and 14.8 MPa or 146 atm (lithostatic pressure), yields approximately 1.3 liters (0.34 gallons) per year.

Gas production rates by microbial degradation of organic materials and anoxic corrosion of steel are likely to be significantly greater than 1.3 liters per year. For example, anoxic corrosion of steels is estimated to yield 0 to 6.3×10^{5} liters of hydrogen per year (Section 6.4, Appendix PA, Attachment MASS). Even if gas production by ***Microbes*** and corrosion was minimal and helium production dominated gas generation, the effects would be of low consequence because of the low total volume.

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

No new information has become available that affects the screening argument; the FEP screening decision remains unchanged. Additional information has been added to the screening discussions.

SCR-6.5.1.9.3 Screening Argument

Based on the composition of the anticipated waste inventory as described in Appendix DATA, Attachment F, the ***Radioactive Gases*** that will be generated in the repository are radon and carbon-14 labeled CO_2 and methane (CH_4).

Appendix DATA, Attachment F indicates that a small amount of carbon-14, 0.73 grams, or 3.26 curies, will be disposed in the WIPP. This amount is insignificant in comparison with the 40 CFR § 191.13 cumulative release limit for carbon-14.

Notwithstanding this comparison, consideration of transport of ***Radioactive Gases*** could potentially be necessary in respect of the 40 CFR § 191.15 individual protection requirements. carbon-14 may partition into CO_2 and methane 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 carbon-14 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 methane may be produced during the microbial degradation of cellulosic waste. However, volumes of methane-14 will be small given the low total inventory of carbon-14, and the tendency of carbon-14 to be incorporated into solid carbonate phases in the repository. Therefore, although transport of carbon-14 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.

Radon 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 (≈ 4 days). ^{222}radon will exhibit secular equilibrium with its parent ^{226}Rn, which has a half-life of 1600 years. Consequently, ^{222}Rn will be produced throughout the 10,000-year regulatory time period. Conservative analysis of the potential ^{222}Rn inventory suggests activities of less than 716 curies at 10,000 years (Bennett 1996).

Direct comparison of the estimated level of ^{222}Rn activity with the release limits specified in 40 CFR § 191.13 cannot be made because the release limits do not cover radionuclides with half-lives less than 20 years. For this reason, production of radon gas can be eliminated from the PA calculations on regulatory grounds. Notwithstanding this regulatory argument, the small potential radon inventory means that the formation and transport of radon 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

No new information has been identified related to the screening of this FEP. It has been modified for editorial purposes.

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 Section 6.4.3.5) 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 Seals*

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 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. 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 actinide retardation on ***Speciation*** in the Culebra is accounted for in PA calculations by sampling over ranges of distribution coefficients (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 Section 6.4.6.2.1.

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 that would change the screening argument has arisen since the submission of the CCA. The original screening discussions have been edited for clarity of expression.

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 actinide solubility, while others, such as citrate, frequently have the opposite influence, often increasing actinide 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. The Fracture-Matrix Transport (FMT) calculations and database input used 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 actinide 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-year 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. (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 Number: W58, W59, and W60
FEP Title: ***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

Precipitation of Secondary Minerals in the disposal room and in geologic units will lead to reductions in nuclide concentrations via the sequestration of radionuclides by coprecipitation and by encapsulation of radionuclide precipitates, and will retard radionuclide transport through sorption. Within the disposal room, metal oxides/oxy-hydroxides will form by corrosion of waste packages and waste components; brucite will form by hydration of MgO backfill;

carbonate minerals will form by carbonation of MgO backfill and cement phases; secondary cement alteration phases will form through brine-cement waste form interactions; and chloride and sulfate minerals will be precipitated due to water uptake during hydration and corrosion reactions. In geologic units above the repository, iron oxides/oxy-hydroxides, carbonates, sulfates may form as groundwaters mix. Mineral precipitation in geologic units above the repository is assumed to be uniform, and in addition to sorbing or sequestering radionuclides, will be beneficial by reducing permeability and slowing the groundwater flow.

During the original WIPP Certification, the EPA questioned the screening argument for ***Kinetics of Precipitation and Dissolution***. The EPA stated in EPA TSD Scope of Performance Assessment regarding ***Kinetics of Precipitation and Dissolution:***

> The screening argument in SCR.2.5.3 appears reasonable to EPA. Initially, EPA thought the argument appeared questionable because the CCA assumed that precipitation reactions are always rapid and complete. As a result, the EPA questioned the gas pressures in the repository, the chemical conditions, and the actinide solubilities. The DOE has since submitted experimental results indicating that the predicted reactions occur and time frames are somewhat rapid. The EPA reconsidered this assessment and concluded that the precipitation assumptions are necessary (and conservative), and are supported by experimental data.

Other than that stated above, no new information that would change the screening argument has arisen since the submission of the CCA. The original text has been edited for clarity of expression.

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.

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 act 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 actinide-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 carbonated and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and EDTA are kinetically very fast, reaching equilibrium in less than one second, which is infinitesimally small on the time scale of the 10,000 year 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 that is predicted based upon equilibrium of the solution phase components with the solubility limiting solid phases. The WIPP actinide source term model, which describes interactions of the waste and brine, is described in detail in 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*** also has been eliminated from PA calculations because no credit is taken for precipitation reactions.

SCR-6.5.4 Sorption

SCR-6.5.4.1 FEP Number: W61, W62, and W63
FEP Title: ***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 & Dewey Lake
SO-C – Beneficial – (W61, W61) 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 for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

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 ***Actinide Sorption*** prevails because of their computational simplicity in comparison with other models (Serne 1992, pp. 238 – 239).

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, 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 that is likely to be involved in sorption mass transfer processes will be small relative to that involved in the bulk dissolution of waste. 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

Chapter 3.0 and CCA 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 Section 6.4.6.2. The model used comprises an equilibrium, sorption isotherm approximation, employing constructed cumulative distribution functions (CDFs) of distribution coefficients (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 years (Wallace et al. 1995). Thus, sorption within the Dewey Lake is accounted for in PA calculations as discussed in 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 Section 6.4.3.6).

SCR-6.5.5 Reduction-Oxidation Chemistry

SCR-6.5.5.1 FEP Number: W64 and W66
FEP Title: ***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 for these FEPs. The screening arguments have not changed. Editorial changes have been made to the discussion.

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, 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 actinide source term model (see Section 6.4.3.5), which estimates the probabilities that particular actinides occur in certain oxidation states.

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 actinide concentrations. Therefore, the ***Effect 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 Dec*ision: 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 years.*

SCR-6.5.5.2.2 Summary of New Information

Large-scale reduction-oxidation fronts have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years. There is no new information that would change the screening decision. Editorial changes have been made to the FEP text to remove reference to other FEP descriptions, screening arguments and screening decisions.

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 Fronts***, 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, uranium, neptunium, and plutonium) will be the most affected by ***Reduction-Oxidation Fronts*** 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 Fronts***. ***Reduction-Oxidation Fronts*** have been observed in natural systems to be the loci for both the mobilization and concentration of radionuclides, such as uranium. For example, during investigations at two uranium deposits at Poços de Caldas, Brazil, uranium was observed by Waber (1991) to be concentrated along ***Reduction-Oxidation Fronts*** at the onset of reducing conditions by its precipitation as uranium oxide. In contrast, studies of the Alligator Rivers uranium deposit in Australia by 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 uranium in its more soluble uranium (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 years. 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 Fronts*** 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 Fronts*** migration suggested by natural system studies. This comparison is considered conservative because the relatively impermeable nature of the Salado suggests that ***Reduction-Oxidation Fronts*** 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 years.

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

The FEP screening argument has been modified from that presented the CCA to include a more complete description of the description has been updated.

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):

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial X}\left(D_{eff}\frac{\partial C}{\partial X}\right) \quad (17)$$

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):

$$D_{eff} = \phi^2 D \quad (18)$$

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 second 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 PA Department, 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 (19), the effective diffusivity D_{eff} in the waste is estimated to be 2 ~ 5 × 10^{-6} cm^2 (7 × 10^{-7} in^2) per second (= 6 ~ 16 × 10^{-3} m^2/year).

Given a time scale of T, the typical diffusion penetration distance (L) can be determined by scaling:

$$L = \sqrt{D_{eff} T} \ . \qquad (19)$$

Using Equation (20), the diffusion penetration distance in the WIPP can be calculated as a function of diffusion time, as shown in Figure SCR-1.

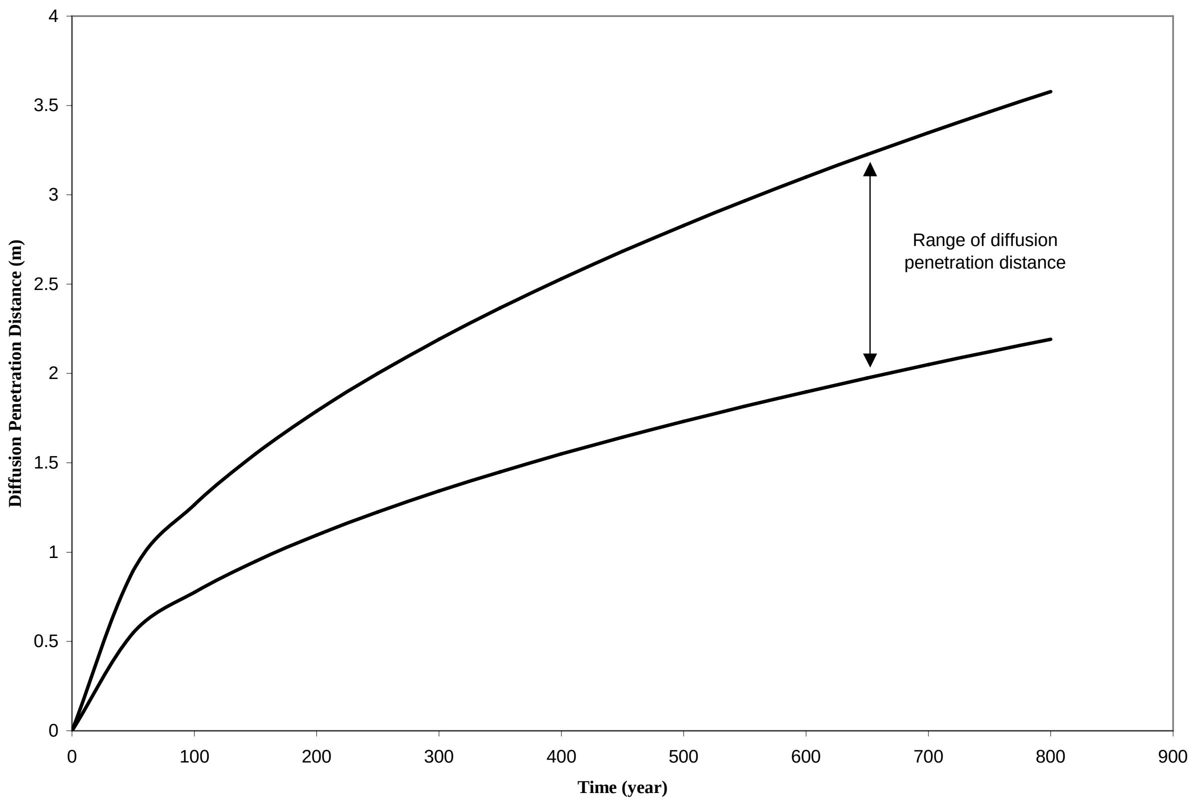

Figure SCR-1. Diffusion Penetration Distance in the WIPP as a Function of Diffusion Time

Direct brine release requires the repository gas pressure to be at least 8 MPA (Stoelzel et al. 1996). The CRA calculations show that it will take at least 100 years for the repository pressure to reach this critical value by gas generation processes. Over this time scale, according to Equation (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 large scale.

The height of waste stacks in the repository after room closure (h) can be calculated by:

$$h = \frac{h_0(1-\phi_0)}{1-\phi} \quad (20)$$

where h_0 and ϕ_0 are the initial height of waste stacks and the initial porosity of wastes, which are assumed to be 4 m and 0.88, respectively, in the WIPP PA. For $\phi = 0.4 - 0.7$, h is estimated to be 0.8 to 1.4 m. This means that molecular diffusion alone can homogenize redox reaction in the vertical dimension of the repository. Therefore, the formation of localized reducing zone is unlikely. The general repository environment will become reducing shortly after room closure, due to metal corrosion and microbial reactions. Therefore, ***Localized Reducing Zones*** can be eliminated from PA calculations on the basis of low consequence to the disposal system.

SCR-6.5.6 Organic Complexation

SCR-6.5.6.1 FEP Number: W68, W69, and W71
FEP Title: ***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

The ***Organic Complexation*** was screened out for the CCA PA, on the basis 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 organics. Although the CRA-2004 calculations include the effects of ***Organic Ligands*** (acetate, citrate, EDTA, and oxalate) on actinide solubility calculations, based on a revised thermodynamic database, the rate at which ***Organic Ligands*** are complexed to actinides is of no consequence to repository performance. Kinetics of ***Organic Ligands*** complexation may be eliminated from PA calculations on the basis of no consequence.

SCR-6.5.6.1.3 Screening Argument

From a PA standpoint, the most important actinides are Th, U, Np, Pu, and Am. Dissolved thorium, uranium, neptunium, plutonium, and americium will speciate essentially 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 due to the presence of Fe(II) and microbes. (Section SOTERM-33 – SOTERM-36).

Some ***Organic Ligands*** can increase the actinide solubilities. An estimate of the complexing agents in the transuranic solidified waste forms scheduled for disposal in WIPP is presented in Appendix DATA, Attachment F Table DATA-F-3.2-24. Acetate, citrate, oxalate, and EDTA were determined to be the only water-soluble and actinide complexing organic ligands present in significant quantities in the TWBIR. 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 actinide 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 TWBIR, nor does it appear in the 2003 update to the TWBIR (Appendix DATA, Attachment F).

The solubility of the actinides is calculated using FMT, a computer code for calculating actinide concentration limits based on thermodynamic parameters. The parameters for FMT are derived both from experimental investigations specifically designed to provide parameter values for this model and from the published literature.

- Although the FSU experimental work on ***Organic Ligands*** complexation showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved actinide 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 organics (Appendix PA, Attachment SOTERM , Sections SOTERM-36 - SOTERM-41).

The CRA-2004 calculations include the effects of organic ligands (acetate, citrate, EDTA, and oxalate) on actinide solubilities in the FMT calculations (Brush and Xiong 2003). The FMT 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, ***2002***b).

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-year 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.

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 and Fulvic Acids** *is incorporated in PA calculations.*

SCR-6.5.6.2.2 Summary of New Information

No new information has been identified for this FEP. Editorial changes have been made to the discussion.

SCR-6.5.6.2.3 Screening Argument

The occurrence of ***Humic and Fulvic Acids*** is incorporated in PA calculations in the models for radionuclide transport by humic colloids (see Section 6.4.6.2.2).

SCR-6.5.7 Chemical Effects on Material Properties

SCR-6.5.7.1 FEP Number: W74 and W76
FEP Title: ***Chemical Degradation of Seals*** (W74)
Microbial Growth on Concrete (W76)

SCR-6.5.7.1.1 Screening Decision: UP

The effects of **Chemical Degradation of Seals** *and of* **Microbial Growth on Concrete** *are accounted for in PA calculations.*

SCR-6.5.7.1.2 Summary of New Information

No new information has been identified for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in DOE (1996a); however the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

SCR-6.5.7.1.3 Screening Argument

The concrete used in the seal systems will degrade due to 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 years 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 Seals*** are accounted for in PA calculations through the CDFs used for seal material permeabilities.

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, 75). Because of the limitations on growth because of 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

As MgO degrades chemically, its physical properties change. Previously, DOE provided a paper by Bynum et al. (1997), which summarizes the experimental results pertaining to chemical degradation of backfill acquired by 1997. The most current MgO data, obtained after the CCA, are summarized in the 2001 MRS Proceedings paper by Snider (2001). The current data show that new MgO will essentially behave as it was designed. Changes have been made to the FEP discussion to reference new experimental results and for editorial purposes.

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 Features, Events, and Processes

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 for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Sections 6.4.5.4 and 6.4.6.2.1.

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 (Sections 6.4.5.4 and 6.4.6.2.1).

SCR-6.6.1.2 FEP Number: W78, W79, W80, and W81
FEP Title: ***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 for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Sections 6.4.3.6 and 6.4.6.2.2.

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. ***Colloid Formation and Stability*** is accounted for in PA calculations through estimates of colloid numbers in the disposal room based on the prevailing chemical conditions (Section 6.4.3.6). Colloid sorption, filtration, and transport in the Culebra are accounted for in PA calculations (Section 6.4.6.2.2).

SCR-6.6.2 Particle Transport

SCR-6.6.2.1 FEP Number: W82, W83,W84, W85, and W86
FEP Title: ***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

Suspensions of Particles larger than colloids are generally unstable and do not persist for very long. The **Rinse** process likely cannot occur under undisturbed conditions because brine flow would not be rapid enough to create a suspension of particles and transport them to the accessible environment. The only reasonable conditions under which suspensions could be formed would be during a drilling event with particles of waste suspended in the drilling fluid are carried to the surface. This effect is covered in PA. Editorial changes have been made to the discussion.

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). 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 Section 6.4.7.1.

SCR-6.6.3 Microbial Transport

SCR-6.6.3.1 <u>FEP Number: W87</u>
<u>FEP Title: ***Microbial Transport***</u>

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 for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

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 (Section 6.4.6.2.2).

SCR-6.6.3.2 <u>FEP Number: W88</u>
<u>FEP Title: ***Biofilms***</u>

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

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. The discussion of this FEP has been updated with recent experimental work.

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 (BNL) 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; Gillow and Francis 2001b; Gillow and Francis 2002a; Gillow and Francis 2002b). As a matter of fact, no apparent formation of stable biofilms was observed in the BNL experiments. The formation of ***Biofilms*** tends to reduce cell suspension and mobility. 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. The screening decision has not changed.

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 radon and carbon-14. Radon gases are eliminated from PA because their inventory is small (<20 Ci; Appendix DATA, Attachment F) and their half-lives are short (<4 days), resulting in insignificant potential for release from the repository. The updated information for the WIPP disposal inventory of carbon-14 (Appendix DATA, Attachment F) indicates that the expected WIPP-scale quantity (3.3 Ci) is 70 percent lower than previously estimated (~13 Ci) in the TWBIR Rev 3 (DOE 1996b). Thus, all CRA-2004 screening arguments for carbon-14 are conservatively bounded by the previous CCA screening arguments.

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 for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

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 (Sections 6.4.5.4 and 6.4.6.2).

SCR-6.7.2 Diffusion

SCR-6.7.2.1 FEP Number: W91 and W92
FEP Title: ***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 for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Chapter 6.0.

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 (Section 6.4.6.2).

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

There is no new information available that affects the screening decision; only minor editorial changes have been made to the FEP discussion.

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

$$J = -D\nabla C - ND\nabla T, \qquad (21)$$

where C is the solute concentration, T is the temperature of the liquid, D is the solute diffusion coefficient, and

$$N = S_T C(1-C), \qquad (22)$$

in which S_T is the Soret coefficient. The mass conservation equation for solute diffusion in a liquid is then

$$\frac{\partial C}{\partial t} = \nabla \bullet \left(D\nabla C + ND\nabla T \right). \qquad (23)$$

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 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 years after waste emplacement. 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 year regulatory period because of the rapid decay of heat-producing nuclides in RH-TRU waste, such as ^{137}Cs, ^{90}Sr, ^{241}Pu, and ^{147}Pm, whose half-lives are approximately 30, 29, 14, and 3 years, 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 W72. 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 50°C (122°F) and that of the surrounding salt to approximately 38°C (100°F) one week after seal emplacement.

However, the concrete seals will act as barriers to fluid flow for at least 100 years after emplacement, and seal permeability will be minimized (Wakeley et al. 1995). As a result, short-term temperature increases associated with concrete hydration will not result in significant Soret diffusion through the seal system.

The maximum temperature rise in the disposal panels will be less than 5°C (9°F) as a consequence of backfill hydration. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. Heat generation by radioactive decay and concrete seal hydration will have decreased substantially after 100 years, 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, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (10.8°F). These calculated maximum heat generation rates resulting from aluminum 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 6°C (10.8°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 relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

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 due to 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***

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 years.*

SCR-6.7.4.2.2 Summary of New Information

No new information relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

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 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 (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 years.

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 relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

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 millivolts and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976, p. 458). Short range potential gradients due to 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 due to 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 <u>FEP Number: W97</u>
<u>FEP Title: ***Chemical Gradients***</u>

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 relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

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 due to 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 and magnesium oxides, 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). Results of the investigations indicate that the salinities of the WIPP brines are sufficient to cause destabilization of mineral fragment colloidal dispersions. Therefore, concentrations of colloidal suspensions originating from concrete within the repository are expected to be extremely low, and are considered in PA calculations.

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 relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

SCR-6.7.5.2.3 Screening Argument

Osmotic Processes, i.e., diffusion of water through a semi permeable 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 semi permeable 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 semi permeable 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 semi-permeable 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 relating to this FEP has been identified. The FEPs discussion has been modified for editorial purposes.

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 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 due to 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

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. Due to the limited spatial extent of enhanced diffusion, its effect on radionuclide transport should be small.

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. Changes have been made to the FEP discussion for clarity and editorial purposes.

SCR-6.7.5.4.3 Screening Argument

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 MgOr, 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.

SCR-6.8 Ecological Features, Events, and Processes

SCR-6.8.1 Plant, Animal, and Soil Uptake

SCR-6.8.1.1 FEP Number: W101, W102, and W103
FEP Title: ***Plant Uptake*** (W101)

Animal Uptake (W102)
Accumulation in Soils (W103)

SCR-6.8.1.1.1 Screening Decision: SO-R
SO-C for 40 CFR 191.15

Plant Uptake, Animal Uptake*, and* ***Accumulation in Soils*** *have been eliminated from compliance assessment calculations for 40 CFR § 191.15 on the basis of low consequence.* ***Plant Uptake*** *and* ***Animal Uptake*** *in the accessible environment have been eliminated from PA calculations for 40 CFR § 191.13 on regulatory grounds.* ***Accumulation in Soils*** *within the controlled area has been eliminated from PA calculations for 40 CFR § 191.13 on the basis of beneficial consequences.*

SCR-6.8.1.1.2 Summary of New Information

DOE has stated that FEPs related to ***Plant Uptake, Animal Uptake***, and ***Accumulation in Soils*** have been eliminated from the compliance assessment calculations on the basis of low consequence. DOE indicated that the screening of these FEPs is justified based upon the results of PA calculations, which show that releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite beds within the Salado Formation. PAs for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 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.

SCR-6.8.1.1.3 Screening Argument

The results of the calculations presented in Section 6.5 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 40 CFR § 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.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 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 Number(s): W104, W105, W106, W107, and W108
FEP Title(s): ***Ingestion*** (W104)
Inhalation (W105)
Irradiation (W106)

Dermal Sorption (W107)
Injection (W108)

SCR-6.8.2.1.1 Screening Decision: SO-R
SO-C for 40 CFR § 191.15

Ingestion, Inhalation, Irradiation, Dermal Sorption*, and* ***Injection*** *have been eliminated from compliance assessment calculations for 40 CFR § 191.15 and Subpart C of 40 CFR Part 191 on the basis of low consequence. FEPs that relate to human uptake in the accessible environment have been eliminated from PA calculations for 40 CFR § 191.13 on regulatory grounds.*

SCR-6.8.2.1.2 Summary of New Information

The DOE stated in the CCA that the results of the PA calculations indicate that releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite beds within the Salado Formation. The DOE further stated that based upon the bounding approach taken for evaluating compliance with EPA's individual protection requirements in 40 CFR § 191.15 and the groundwater protection requirements in Subpart C of 40 CFR § 191, these abovementioned exposure pathways were found to be of low consequence. However, the analysis did not include analysis of doses from other potential exposure pathways such as stock consumption or irrigation. These weaknesses were remedied by DOE's submittal of a more detailed dose analysis, which included all of the appropriate additional pathways (DOE 1997c).

In both the PAVT and the CCA calculations (DOE 1997a, 1997b, 1997c) a very conservative bounding-analysis approach was used to estimate potential doses. Using this approach, the calculated maximum potential dose (millirems) to any internal organ due to beta particle and photon radioactivity from man-made radionuclides in drinking water was 2.9×10^{-4} in the PAVT and 4.2×10^{-3} for the CCA. Further, the annual effective dose equivalent to the total body due to beta particle and photon radioactivity is 1.5×10^{-5} in the CCA and 2.3×10^{-4} for the CCA. All of these values are well below the acceptable standard of 4 millirems per year as specified in 40 CFR § 141.16(a). Finally, the calculated maximum potential doses (millirems) to an individual due to meat consumption, vegetable consumption, and inhalation of resuspended irrigated soil are 2.7×10^{-7}, 0.031, and 2.1×10^{-5}, respectively, in the PAVT and 3.3×10^{-8}, 0.46, 3.1×10^{-4}, respectively, in the CCA. All of these values are well below the individual protection standard, an annual committed effective dose of 15 millirems as specified in 40 CFR § 191.15(a). Therefore, the original screening decisions remain valid, and no changes have been made to the FEP screening arguments or decisions.

SCR-6.8.2.1.3 Screening Argument

As described in Section 8.1.1, 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 40 CFR § 191.15 and the groundwater protection requirements in Subpart C of 40 CFR Part 191 (see Sections 8.1.2.2 and 8.2.3), 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.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 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.

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