# APPENDIX PA

# ATTACHMENT SCR

# Table of Contents

## List of Figures



## List of Tables

# 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 | transmissivity |

| | |
|---|---|
| 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<br>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<br>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<br>SO-C in Culebra |
| N25 | ***Fracture Flow*** | No | No change | UP |
| N27 | ***Effects of Preferential Pathways*** | No | No change | UP<br>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<br>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<br>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)<br>DP (Future) |
| H2 | ***Potash Exploration*** | No | Updated | SO-C (HCN)<br>DP (Future) |
| H4 | ***Oil and Gas Exploitation*** | No | Updated | SO-C (HCN)<br>DP (Future) |
| H8 | ***Other Resources*** | No | Updated | SO-C (HCN)<br>DP (Future) |
| H9 | ***Enhanced Oil and Gas Recovery*** | No | Updated | SO-C (HCN)<br>DP (Future) |
| H3 | ***Water Resources Exploration*** | No | Both italicized and FEP text revised. | SO-C (HCN)<br>SO-C (Future) |
| H5 | ***Groundwater Exploitation*** | No | Both italicized and FEP text revised. | SO-C (HCN)<br>SO-C (Future) |
| H6 | ***Archaeological Investigations*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H7 | ***Geothermal*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H10 | ***Liquid Waste Disposal*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H11 | ***Hydrocarbon Storage*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H12 | ***Deliberate Drilling Intrusion*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H13 | ***Conventional Underground Potash Mining***<br><br>***Formerly Called "Potash Mining"*** | No | Name changed from "Potash Mining" to "Conventional Underground Potash Mining." Both italicized and FEP text revised. | UP (HCN)<br>DP (Future) |
| H14 | ***Other Resources*** | No | Both italicized and FEP text revised. | SO-C (HCN)<br>SO-R (Future) |
| H15 | ***Tunneling*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H16 | ***Construction of Underground Facilities (for Example Storage, Disposal, Accommodation)*** | No | Both italicized and FEP text revised. | SO-R (HCN)<br>SO-R (Future) |
| H17 | ***Archaeological Excavations*** | No | Both italicized and FEP text revised. | SO-C (HCN)<br>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)<br>SO-R (Future) |
| H19 | ***Explosions for Resource Recovery*** | No | Both italicized and FEP text revised. | SO-C (HCN)<br>SO-R (Future) |
| H20 | ***Underground Nuclear Device Testing*** | No | No changes | SO-C (HCN)<br>SO-R (Future) |
| H21 | ***Drilling Fluid Flow*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>DP (Future) |
| H22 | ***Drilling Fluid Loss*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>DP (Future) |
| H23 | ***Blowouts*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>DP (Future) |
| H24 | ***Drilling-Induced Geochemical Changes*** | No | Reference to other FEPs removed from FEP and italicized text | UP (HCN)<br>DP (Future) |
| H25 | ***Oil and Gas Extraction*** | No | No changes | SO-C (HCN)<br>SO-R (Future) |
| H26 | ***Groundwater Extraction*** | No | No changes | SO-C (HCN)<br>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)<br>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)<br>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)<br>SO-C (Future) |
| H30 | ***Fluid-injection Induced Geochemical Changes*** | No | Reference to other FEPs removed from FEP and italicized text. | UP (HCN)<br>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)<br>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)<br>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)<br>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)<br>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)<br>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)<br>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)<br>SO-R (Future) |
| H39 | ***Changes in Groundwater Flow Due to Explosions*** | No | No changes | SO-C (HCN)<br>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)<br>SO-R (Future) |
| H41 | ***Surface Disruptions*** | Yes | Reference to other FEPs removed from italicized text, additional information added to FEP text. | UP (HCN)<br>SO-R (Future) |
| H42 | ***Damming of Streams or Rivers*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>SO-R (Future) |
| H43 | ***Reservoirs*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>SO-R (Future) |
| H44 | ***Irrigation*** | No | Reference to other FEPs removed from FEP and italicized text | SO-C (HCN)<br>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)<br>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)<br>SO-R (Future) |
| H47 | ***Greenhouse Gas Effects*** | No | No changes | SO-R (HCN)<br>SO-R (Future) |
| H48 | ***Acid Rain*** | No | No changes | SO-R (HCN)<br>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)<br>SO-R (Future) |
| H50 | ***Coastal Water Use*** | No | No changes | SO-R (HCN)<br>SO-R (Future) |
| H51 | ***Sea water Use*** | No | No changes | SO-R (HCN)<br>SO-R (Future) |
| H52 | ***Estuarine Water Use*** | No | No changes | SO-R (HCN)<br>SO-R (Future) |
| H53 | ***Arable Farming*** | No | No changes | SO-C (HCN)<br>SO-R (Future) |
| H54 | ***Ranching*** | No | No changes | SO-C (HCN)<br>SO-R (Future) |
| H55 | ***Fish Farming*** | No | No changes | SO-R (HCN)<br>SO-R (Future) |
| H56 | ***Demographic Change and Urban Development*** | No | Reference to other FEPs removed from FEP and italicized text. | SO-R (HCN)<br>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)<br>DP (Future) |
| H58 | ***Solution Mining for Potash*** | Yes | New FEP, ***Solution Mining*** was contained in various other FEPs – see H13 | SO-R (HCN)<br>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)<br>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 Deformation

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 $5 \times 10^{16}$.

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 $K_d$s obtained with the saline solutions were somewhat lower than those obtained with the Culebra fluids. The $K_d$s recommended by Brush and Storz (1996) were used for the CRA-2004 PA. These $K_d$s 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 $2 \times 10^{-13}$ impacts per square kilometer per year). Using observations from the Canadian Shield, Hartmann (1965, p. 161) estimated a frequency of between $0.8 \times 10^{-13}$ and $17 \times 10^{-13}$ 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 $1.3 \times 10^{-12}$ 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 $17 \times 10^{-13}$ 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 $4 \times 10^{-12}$ 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

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

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:

$$F_D \propto D^{-1.8}, \quad (2)$$

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

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

and

$$f(D) = F_1 \times 1.8 \times D^{-2.8}, \qquad (4)$$

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

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

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 <u>FEP Number: H17</u>
<u>FEP Title: ***Archeological Excavations***</u>

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 $K_d$s 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 $4 \times 10^{-5}$. 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 $4.5 \times 10^3$ 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 $23 \times 10^3$ 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 $7 \times 10^5$ $m^3$ ($2.47 \times 10^7$ $ft^3$) 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 $1 \times 10^{-9}$ $m^2$ ($4 \times 10^{-8}$ in.)). Cement plugs (of permeability $1 \times 10^{-17}$ $m^2$ ($4 \times 10^{-16}$ 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

$$\overline{v} - -\frac{k}{\mu}[\nabla p - \rho \overline{g}], \qquad (7)$$

where

| | | | |
|---|---|---|---|
| $v$ | = | Darcy velocity vector | (m s$^{-1}$) |
| $k$ | = | intrinsic permeability | (m$^2$) |
| $\mu$ | = | fluid viscosity | (pa s) |
| $\nabla p$ | = | gradient of fluid pressure | (pa m$^{-1}$) |
| $\rho$ | = | fluid density | (kg m$^{-3}$) |
| $g$ | = | gravitational acceleration vector | (m s$^{-2}$) |

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

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

where

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

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

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

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 $64 \times 10^6$ pascals (9,600 psi), with permeability of about $2 \times 10^{-14}$ $m^2$ ($2.1 \times 10^{-13}$ $ft^2$) and thickness of about 210 m (689 ft). The Strawn, 3,900 m (12,795 ft) below the land surface, has the lowest pressures ($35 \times 10^6$ pascals (5,000 psi), which is lower than hydrostatic) and highest permeability ($10^{-13}$ $m^2$ ($1.1 \times 10^{-12}$ $ft^2$)) 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 $10^{-11}$ $m^2$ ($1.1 \times 10^{-10}$ $ft^2$)) representing silty sand, a borehole radius of 0.25 m (.82 ft), and a fluid pressure in the Culebra of $0.88 \times 10^6$ 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 $1.4 \times 10^{-5}$ $m^3/s$ (0.22 gpm), and the Strawn was calculated to receive water from the Culebra at about $1.5 \times 10^{-6}$ $m^3/s$ (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 $3 \times 10^{-20}$ $m^2$ ($3.2 \times 10^{-19}$ $ft^2$) 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 $1.0 \times 10^{-17}$ $m^2$ ($1.1 \times 10^{-16}$ $ft^2$) 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).