Sandia National Laboratories
Waste Isolation Pilot Plant

Features, Events and Processes Assessment for the Compliance Recertification Application – 2009, Revision 0

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1. 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 (TRU) 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) (DOE 1996a). These calculations demonstrated that the predicted releases of radionuclides to the accessible environment would not exceed those allowed by the EPA standard, given the assumptions and understanding of the disposal system at that time.

To assure that WIPP's compliance is based on the most recent information, the WIPP Land Withdrawal Act (LWA) (U.S. Congress 1996) requires that the WIPP compliance with the EPA's disposal standards be recertified every five years. As such, the DOE submitted its first recertification application that demonstrates continued compliance with EPA's requirements for radioactive waste disposal in March of 2004 (CRA-2004) (DOE 2004). As part of the CRA-2004, a reassessment of the FEPs baseline was conducted to assure that any new information pertaining to the basis of compliance was properly included (or excluded) in PA (Wagner et al. 2003). The FEPs reassessment for the CRA-2004 was a comprehensive look at the FEPs baseline, and considered all changes and their potential to affect information within the FEPs baseline. The 2004 FEPs reassessment involved bringing the baseline up to date by considering all changes and new information since submittal of the CCA in 1996, roughly a seven year period. After a two-year review period, the EPA recertified the WIPP's continued compliance March 29, 2006 (EPA 2006a). As part of their review of the CRA, the EPA published Compliance Application Review Documents (CARDs) and Technical Support Documents (TSDs) that document their review of important components of the CRA-2004. The CARD for Section 194.32 (EPA 2006b) and the TSD (EPA 2006c) were specifically targeted at the FEPs reassessment. EPA's review concluded that the FEPs reassessment and documentation provided in the CRA-2004 was acceptable and appropriately accounted for changes since the initial certification of the WIPP.

As with previous compliance applications, it is incumbent upon the DOE to confirm that the FEPs basis is adequate and to account for any new or proposed changes to the PA system. Such changes are evaluated according to Sandia National Laboratories Specific Procedure (SP) SP 9-4, "Performing FEPs Baseline Impact Assessments for Planned and Unplanned Changes." Through this procedure, the FEPs baseline is managed and updated systematically over time, rather than updated immediately prior to recertification, as was done for the CRA-2004 (Wagner et al, 2003). The method provided in SP 9-4 is preferred as it provides for constant maintenance of the baseline, and provides assurance that PA analyses done in the interim between recertification applications are based on a valid and appropriate FEPs basis. An additional benefit of this method is that for the current recertification application, all that is needed is a "roll-up" of the FEPs assessments since the last recertification to document the changes to the FEPs basis, and a review of new information that originates outside the PA program. As such, this document presents the roll-up of the FEPs assessments that have been conducted since the CRA-2004, and the incorporation of any new information that has not been reviewed as an SP-9.4 FEPs assessment. The results of this analysis thereby document the FEPs basis for the CRA-2009.

2. FEPS IMPACT ASSESSMENT APPROACH

As noted in the Introduction, the purpose of this document is to determine if the current FEPs baseline remains appropriate in consideration of new information that has become available since the most recent certification decision. The FEPs baseline is represented by: (1) the most current version of Attachment SCR (currently, CRA-2004 Appendix PA, Attachment SCR); (2) related information published by the EPA in their TSDs and CARDs of the most recent certification decision; and (3) FEPs assessment results and other information in Sandia Records Package 543545. This analysis will evaluate the FEPs baseline and identify areas of change in four steps.

First, this analysis will evaluate changes to the PA baseline since the CRA-2004 by reviewing all FEPs assessments that have been conducted under SP 9-4 since EPA's most recent recertification (EPA 2006a). This information consists of the contents of Records Package 543545. This will capture all changes that have been actively pursued by the DOE.

Second, this analysis will evaluate new information originates outside the WIPP PA program. This information may come from DOE monitoring programs, updated waste inventory data, EPA evaluations of compliance (e.g., EPA Compliance Application Review Documents [CARDs]), or other outside sources of information that may be relevant to the WIPP's certification basis. Changes to human activities will be of primary interest because they have the most potential for change. For example, the natural system is well defined and changes occur very slowly if at all, however technological advancements that relate to resource extraction may occur in a very short period of time. As mentioned, this assessment will also look at any new data included in the CRA-2009 PA. This aspect of the assessment will focus on the updated inventory for the CRA-2009. While the inventory for the CRA-2009 is essentially the same as that used in the Performance Assessment Baseline Calculation (PABC) (Leigh et al., 2005a), this inventory has not been incorporated into the FEPs baseline, as the EPA required the use of this updated inventory (Leigh et al. 2005b) after the CRA-2004 Appendix PA, Attachment SCR was published. Therefore, FEPs that use inventory information will be updated as necessary.

Third, this assessment will review all other FEPs for "housekeeping" and general editorial purposes. Such changes will be limited to improvements and clarifications to FEPs descriptions and screening arguments.

Finally, this assessment will include any changes to the FEPs basis that result from EPA-approved changes to the baseline.

For this evaluation, each FEP presented in Attachment SCR is reviewed to determine if any changes are merited in consideration of new information from the sources listed above. FEPs are updated as needed and combined with those generated from step 1 of this analysis. FEPs not requiring update are noted as such and included in the CRA-2009 Appendix SCR as unchanged and will not be included in this report.

This report continues to use the same screening classifications used since the WIPP CCA: "UP" is the screening classification that represents those FEPs incorporated in <u>undisturbed performance</u> scenarios. The "DP" screening classification represents FEPs incorporated in <u>disturbed performance</u> scenarios. "SO-C" represents those FEPs the have been excluded or <u>screened out</u> of any scenario due to either low-, no-, or beneficial <u>consequence</u>. "SO-R" represents those FEPs that

have been <u>screened out</u> due to <u>regulatory</u> provision, and "SO-P" represents those FEPs that have been <u>screened out</u> due to low <u>probability</u>.

2.1 REVIEW OF SP-9-4 FEPS ASSESSMENTS

Section 2.4.8 of SP 9-4 requires that the results of all FEPs assessments be placed in Sandia Records Package number 543545. Therefore, the contents of this records package must be obtained to begin this review for the CRA-2009. Records package 543545 includes the following FEPs assessments:

1. FEPs Assessment for the Panel Closure System Redesign (ERMS 543210)

2. FEPs Assessment for Changes Described in AP-132 (ERMS 546933)

3. FEPs Assessment for Changes Described in AP-137 (ERMS 548816)

The remainder of this section will discuss the scope and results of each of these assessments.

2.1.1 FEPs Assessment for the Panel Closure System Redesign

The FEPs assessment for the Panel Closure System (PCS) redesign (Kirkes 2006a) did not identify any screening decision errors inconsistencies within the FEPs baseline at the time of the assessment. Recommendations were made, however to clarify between FEPs that relate to shaft seals and those that relate to the PCS. These recommendations were documented in Kirkes (2006b), and state that during the FEPs reevaluation for the CRA-2009, FEPs should be titled so that it is clear that they are describing the shaft seals. Also, FEPs that currently relate to the PCS, should be titled such that it is clear they relate to the panel closures, and not shaft seals. Finally, those FEPs that relate to both the panel closure system and the shaft seals should be split into separate FEPs.

Table 2-1 below lists the FEPs that are changed as a result of the recommendations in Kirkes (2006b):

Table 2-1 FEPs Affected by the PCS Redesign FEPs Assessment			
CRA-2004 FEP Title		**CRA-2009 FEP Title**	
W6	Seal Geometry	W6	Shaft Seal Geometry
W7	Seal Physical Properties	W7	Shaft Seal Physical Properties
W8	Seal Chemical Composition	W8	Shaft Seal Chemical Composition
W17	Radiological Effects on Seals	W17	Radiological Effects on Shaft Seals
W36	Consolidation of Seals	W36	Consolidation of Shaft Seals
W37	Mechanical Degradation of Seals	W37	Mechanical Degradation of Shaft Seals
W74	Chemical Degradation of Seals	W74	Chemical Degradation of Shaft Seals
		W109	Panel Closure Geometry
		W110	Panel Closure Physical Properties
		W111	Panel Closure Chemical Composition
		W112	Radiological Effects on Panel Closures
		W113	Consolidation of Panel Closures
		W114	Mechanical Degradation of Panel Closures

The following presents revised screening arguments and decisions for the FEPs listed above. These revised FEPs replace CRA-2004 screening arguments in Attachment SCR for the CRA-2009. It should be noted that none of these FEPs require changes to PA models or codes; current PA models represent these FEPs in their current configurations.

2.1.1.1 **FEP Number:**   **W6, W7, W109, and W110**
         FEP Title: **Shaft Seal Geometry (W6)**
                          Shaft Seal Physical Properties (W7)
                          Panel Closure Geometry (W109)
                          Panel Closure Physical Properties (W110)

Screening Decision: **UP**

The Shaft Seal Geometry, Shaft Seal Physical Properties, Panel Closure Geometry, and Panel Closure Physical Properties are accounted for in PA calculations.

Summary of New Information
FEPs related to seals (generic) have been renamed to differentiate between panel closures and shaft seals. While analyzing the impacts of redesigned panel closures on the FEPs baseline, it was concluded that the current FEPs do not accurately represent these to seal types (Kirkes 2006a). Because a redesigned panel closure system has not been approved or implemented, new screening arguments are not appropriate at this time, but if the request for a redesigned panel closure system is approved, revised screening arguments may be warranted to better describe the panel closure physical properties (i.e., crushed salt versus concrete).

Screening Argument
Seal (shaft seals, panel closures, and drift closures) characteristics, including *Shaft Seal Geometry, Panel Closure Geometry, Seal Physical Properties*, and *Panel Closure Physical Properties* are described in Section 3.3.2 of the CCA (DOE 1996a) and are accounted for in PA calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the shaft seal and panel closure materials (see Section PA-4.2.7 and PA-4.2.8, Appendix PA).

2.1.1.2 FEPs Number: **W8, W111**
        FEP Title: **Shaft Seal Chemical Composition (W8)**
                                   Panel Closure Chemical Composition (W111)

Screening Decision: **SO-C Beneficial**

The Seal Chemical Composition has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

Summary of New Information
These FEPs have been re-titled as a result of the FEPs analysis conducted for the Panel Closure Redesign planned change request. (Kirkes 2006a)

Screening Argument
Shaft seal and panel closure characteristics, including Shaft Seal and Panel Closure Geometry and Shaft Seal and Panel Closure Physical Properties, are described in CCA Chapter 3.0 and are accounted for in PA calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials. The effect of Shaft Seal and Panel Closure Chemical Composition on actinide speciation and mobility has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

Repository Seals (Shaft and Panel Closures)
Certain repository materials have the potential to interact with groundwater and significantly alter the chemical speciation of any radionuclides present. In particular, extensive use of cementitious materials in the seals may have the capacity to buffer groundwaters to extremely high pH (for example, Bennett et al. 1992, pp. 315 - 325). At high pH values, the speciation and adsorption behavior of many radionuclides is such that their dissolved concentrations are reduced in comparison with near-neutral waters. This effect reduces the migration of radionuclides in dissolved form.

Several recent publications describe strong actinide (or actinide analog) sorption by cement (Altenheinhaese et al. 1994; Wierczinski et al. 1998; Pointeau et al. 2001), or sequestration by incorporation into cement alteration phases (Gougar et al. 1996, Dickson and Glasser 2000). These provide support for the screening argument that chemical interactions between the cement seals and the brine will be of beneficial consequence to the performance of the disposal system.

The effects of cementitious materials in shaft seals and panel closures on groundwater chemistry have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

2.1.1.3 FEP Number: **W17, W112**
        FEP Title: **Radiological Effects on Seals (W17)**
                                   Radiological Effects on Panel Closures (W112)

Screening Decision: SO-C

Radiological Effects on Shaft Seals and Panel Closures have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Summary of New Information
These FEPs have been re-titled as a result of the FEPs analysis conducted for the Panel Closure Redesign planned change request (Kirkes 2006a), and the screening arguments for these FEPs have been updated to include references to the radionuclide inventory used for CRA-2009 PA calculations.

Screening Argument
Ionizing radiation can change the physical properties of many materials. Strong radiation fields could lead to damage of waste matrices, brittleness of the metal containers, and disruption of any crystalline structure in the seals. The low level of activity of the waste in the WIPP is unlikely to generate a strong radiation field. According to the inventory data presented in Leigh et al. (2005a), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 curies reported in the CCA to 2.48×10^6 curies in the CRA-2004 to 2.32×10^6 curies in the CRA-2009. This decrease will not change the original screening argument. Furthermore, PA calculations assume instantaneous container failure and waste dissolution according to the source-term model (see CCA Chapter 6.0, Sections 6.4.3.4, 6.4.3.5, and 6.4.3.6). Therefore, *Radiological Effects on the Properties Shaft Seals and Panel Closures* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.1.1.4	FEP Number:	W36, W37, W113, W114
	FEP Title:	**Consolidation of Shaft Seals (W36)**
		Mechanical Degradation of Shaft Seals (W37)
		Consolidation of Panel Closures (W113)
		Mechanical Degradation of Panel Closures (W114)

Screening Decision: UP

Consolidation of Seals and Mechanical Degradation of Seals are accounted for in PA calculations.

Summary of New Information
These FEPs have been re-titled as a result of the FEPs analysis conducted for the Panel Closure Redesign planned change request. (Kirkes 2006a)

Screening Argument
Mechanical Degradation of Shaft Seals and Panel Closures and the Consolidation of Shaft Seals and Panel Closures are accounted for in PA calculations through the permeability range assumed for the seal system (CRA-2009 Appendix PA, Section PA-4.2.7 and PA-4.2.8).

The site investigation program has also involved the drilling of boreholes from within the excavated part of the repository. Following their use for monitoring or other purposes, these Underground Boreholes will be sealed where practical, and Salt Creep will also serve to consolidate the seals and to close the boreholes. Any boreholes that remain unsealed will connect the repository to anhydrite interbeds within the Salado, and thus provide potential pathways for radionuclide transport. PA

calculations account for fluid flow to and from the interbeds by assuming that the DRZ has a permanently enhanced permeability that allows flow of repository brines into specific anhydrite layers and interbeds. This treatment is also considered to account for the effects of any unsealed boreholes.

2.1.1.5   FEP Number: W74, W115
FEP Title: **Chemical Degradation of Shaft Seals (W74)**
                      Chemical Degradation of Panel Closures (W115)

Screening Decision: **UP**

The effects of Chemical Degradation of Shaft Seals and Panel Closures are accounted for in PA calculations.

Summary of New Information
These FEPs have been re-titled as a result of the FEPs analysis conducted for the Panel Closure Redesign planned change request. (Kirkes 2006a)

Screening Argument
The concrete used in the shaft seal and panel closure systems will degrade due to chemical reaction with the infiltrating groundwater. Degradation could lead to an increase in permeability of the seal system. The main uncertainties with regard to cement degradation rates at the WIPP are the effects of groundwater chemistry, the exact nature of the cementitious phases present, and the rates of brine infiltration. The PA calculations take a conservative approach to these uncertainties by assuming a large increase in permeability of the concrete seals only a few hundred years after closure. These permeability values are based on seal design considerations and consider the potential effects of degradation processes. Therefore, the effects of Chemical Degradation of Shaft Seals and Panel Closures are accounted for in PA calculations through the CDFs used for seal material permeabilities.

Concrete can be inhabited by alkalophilic bacteria, which could produce acids, thereby accelerating the seal degradation process. Nitrification processes, which will produce nitric acid, tend to be aerobic, and will be further limited at the WIPP by the low availability of ammonium in the brines (Pedersen and Karlsson 1995, 75). Because of the limitations on growth because of the chemical conditions, it is likely that the effects of Microbial Growth on Concrete will be small. The effects of such microbial activity on seal properties are, therefore, implicitly accounted for in PA calculations through the CDFs used for seal material permeabilities.

2.1.2   Assessment for Changes Described in AP-132 (ERMS 546933)

Analysis Plan AP-132 describes the changes to the PA modeling system planned for PA calculations. In summary, these changes include:

1) Healing of the disturbed rock zone (DRZ)
2) Quantity of brine in the DRZ

3) Including the hydration of Magnesium Oxide (MgO) and other reactions that affect brine saturation in BRAGFLO
4) A new parameter distribution for the waste shear strength
5) Revised parameter for the duration of direct brine release

The FEPs assessment for the changes described in AP-132 evaluated each of these changes for impacts to the FEPs baseline according to the methodology in SP-9-4. The conclusion of the assessment states that, "This FEPs impact assessment has been conducted according to SP 9-4 and has completed the steps necessary to determine if the changes planned in AP-132 create any inconsistencies or conflicts with the current FEPs baseline. No screening decision errors have been identified." Therefore, no changes to FEPs screening decision or arguments are warranted as a result of these changes.

2.1.3 Assessment for Changes Described in AP-137 (ERMS 548816)

Analysis Plan AP-137 describes the changes to the PA modeling system planned for PA calculations to be included in the CRA-2009. In summary, these changes include modification and improvements to:

1) The parameter representing the maximum flow duration for direct brine release (DBR)
2) The sampling method applied to the humid and inundated degradation rates for cellulose, plastic and rubber
3) Additional chemistry parameters
4) Capillary pressure and relative permeability models
5) Computer codes used in the PA
6) An update to the drilling rate parameter (GLOBAL:LAMBDAD)
7) Error corrections discovered in PA codes and input values

No screening decision conflicts or impacts have been identified as a result of this review. Because each of these changes represents the implementation of a FEP (or FEPs) that is already accounted for in PA (screened in), no changes to the FEPs basis are warranted.

2.2 REVIEW OF NEW INFORMATION ORIGINATING OUTSIDE PERFORMANCE ASSESSMENT

This section will review information that originates outside the WIPP PA program and determine if any changes to FEPs screening decisions and arguments are warranted. Examples of this type of information include changes in technology as it relates to resource exploration, development, and exploitation. This evaluation will primarily focus on human-initiated events and process (EPs), although some natural FEPs may be affected by new data. (e.g., new seismic data may need to be incorporated). Sources of information for this review will include the Delaware Basin Monitoring Annual Report (DBMAR) for 2007 (DOE 2007a), and independent contractor reports. Additionally, any new information that has become available after the publishing of the DBMAR 2007 will be considered. Finally, while the inventory used for PA calculations for the CRA-2009 is very similar to that used for the CRA-2004, some elements have changed. Therefore, FEPs that use inventory data will be evaluated and updated as necessary with the same inventory information used for the CRA-2009 PA calculations (Leigh et al. 2005b).

2.2.1 Delaware Basin Monitoring Annual Report for 2007

FEPs from the 2004 SCR were reviewed to determine if any required specific data and information from the DBMAR-2007. This review concluded that the following FEPs were in need of update.

2.2.1.1 **FEP Number:** N12
FEP Title: **Seismic Activity**

Screening Decision: UP

The postclosure effects of seismic activity on the repository and the DRZ are accounted for in PA calculations.

Summary of New Information
Seismic monitoring conducted for the WIPP since the CRA-2004 continues to record small events at distance from the WIPP, and these events are mainly in areas associated with hydrocarbon production. Three seismic events (magnitude 2.4 on January 27, 2006; magnitude 3.8 on December 19, 2005; and magnitude 3.6 on May 23, 2004) occurred within 300 km of the WIPP (see DOE 2005, 2006, 2007b). These events did not cause any damage at the WIPP.

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

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).

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

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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.

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 of the CCA (DOE 1996a) contains additional discussion of seismic activity and risk in the WIPP region.

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

Three source regions were used in calculating seismic risk: the Rio Grande Rift, the Central Basin Platform, and part of the Delaware Basin province (including the Los Medaños). Using conservative assumptions about the maximum magnitude event in each zone, the study indicated a return period of about 10,000 years (annual probability of occurrence of 10^{-4}) for events producing ground accelerations of 0.1 gravities. Ground accelerations of 0.2 gravities would have an annual probability of occurrence of about 5×10^{16}.

The results of the seismic risk study and the observations of damage in mines due to groundshaking give an estimated annual probability of occurrence of between 10^{-6} and 10^{-8} for events that could increase the permeability of the DRZ. The DRZ is accounted for in PA calculations as a zone of permanently high permeability (see CRA-2009 Appendix PA, Section PA-4.2.4); this treatment is considered to account for the effects of any potential seismic activity.

2.2.1.2 FEP Number(s):   **H3 and H5**
         FEP Title(s):   **Water Resources Exploration (H3)**
                                              Groundwater Exploitation (H5)

Screening Decision: **SO-C (HCN)**
                                        SO-C (Future)

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

Summary of New Information
The Delaware Basin Monitoring Program records and tracks the development of deep and shallow wells within the vicinity of the WIPP. Updated drilling data is reported annually in the Delaware Basin Monitoring Annual Report (DOE 2007a). While this information has been updated since the last recertification, it does not result in a change in the screening arguments or decisions of these FEPs.

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 2007 Annual Report (DOE 2007a), 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.

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 (DOE 1996a). The distribution of groundwater wells in the Delaware Basin is included in CCA

Appendix USDW, Section USDW.3 (DOE 1996a). *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.

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 includes drilling associated with *Water Resources Exploration, Potash Exploration*, and *Groundwater Exploitation* in calculations to determine the rate of future shallow drilling in the Delaware Basin. However, the effects of such events are not included in PA calculations due to low consequence to the performance of the disposal system.

2.2.1.3	FEP Number(s):	W23 and W24
	FEP Title(s):	*Subsidence* (W23)
		Large Scale Rock Fracturing (W24)

Screening Decision(s):	SO-C (W23)
	SO-P (W24)

*Fracturing within units overlying the Salado and surface displacement caused by **Subsidence** associated with repository closure have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The potential for excavation or repository-induced **Subsidence** to create **Large-Scale Rock Fracturing** and fluid flow paths between the repository and units overlying the Salado has been eliminated from PA calculations on the basis of the low probability of occurrence over 10,000 years.*

Summary of New Information
Continuous survey data, reported annually, reaffirm that *Subsidence* is minimal and near the accuracy of the survey itself (see annual COMPs reports in CRA-2009 Appendix DATA).

Screening Argument
Instability of the DRZ could to lead to localized *Roof Falls* in the first few hundred years. If instability of the DRZ causes *Roof Falls*, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep and the local lithologies.

In the long term, the effects of *Roof Falls* in the repository are likely to be minor because *Salt Creep* will reduce the void space and the potential for roof falls as well as leading to healing of any roof material that has fallen into the rooms. Because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the PA assumed that a higher permeability zone remained for the long term. The PAVT modified the DRZ permeability to a sampled range. Thus, the potential effects of *Roof Falls* on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ.

The amount of *Subsidence* that can occur as a result of *Salt Creep* closure or roof collapse in the WIPP excavation depends primarily on the volume of excavated rock, the initial and compressed porosities of the various emplaced materials (waste, backfill, panel and drift closures, and seals), the amount of inward creep of the repository walls, and the gas and fluid pressures within the repository. The DOE (Westinghouse 1994) has analyzed potential excavation-induced subsidence with the primary objective of determining the geomechanical advantage of backfilling the WIPP excavation. The DOE (Westinghouse 1994, pp. 3-4 to 3-23) used mass conservation calculations, the influence function method, the National Coal Board empirical method, and the two-dimensional, finite-difference code, Fast Lagrangian Analysis of Continua (FLAC) to estimate *Subsidence* for conditions ranging from no backfill to emplacement of a highly compacted crushed salt backfill. The DOE (Westinghouse 1994, pp. 2-17 to 2-23) also investigated *Subsidence* at potash mines located near the WIPP site to gain insight into the expected *Subsidence* conditions at the WIPP and to calibrate the subsidence calculation methods.

Subsidence over potash mines will be much greater than subsidence over the WIPP because of the significant differences in stratigraphic position, depth, extraction ratio, and layout. The WIPP site is located stratigraphically lower than the lowest potash mine, which is near the base of the McNutt Potash Member (hereafter called the McNutt). At the WIPP site, the base of the McNutt is about 150 m (490 ft) above the repository horizon. Also, the WIPP rock extraction ratio in the waste disposal region will be about 22 percent, as compared to 65 percent for the lowest extraction ratios within potash mines investigated by the DOE (Westinghouse 1994, p. 2-17).

The DOE (Westinghouse 1994, p. 2-22) reported the maximum total *Subsidence* at potash mines to be about 1.5 m (5 ft). This level of *Subsidence* has been observed to have caused surface fractures. However, the DOE (Westinghouse 1994, p. 2-23) found no evidence that *Subsidence* over potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the landsurface. The level of disturbance caused by *Subsidence* above the WIPP repository will be less than that associated with potash mining and thus, by analogy, will not create fluid flow paths between the repository and the overlying units.

The various *Subsidence* calculation methods used by the DOE (Westinghouse 1994, pp. 3-4 to 3-23) provided similar and consistent results, which support the premise that *Subsidence* over the WIPP will be less than *Subsidence* over potash mines. Estimates of maximum *Subsidence* at the land surface for the cases of no backfill and highly compacted backfill are 0.62 m (2 ft) and 0.52 m (1.7 ft), respectively. The mass conservation method gave the upper bound estimate of *Subsidence* in each case. The surface topography in the WIPP area varies by more than 3 m (10 ft), so the expected amount of repository-induced *Subsidence* will not create a basin, and will not affect surface hydrology significantly. The DOE (Westinghouse 1994, Table 3-13) also estimated *Subsidence* at the depth of the Culebra using the FLAC model, for the case of an empty repository (containing no waste or backfill). The FLAC analysis assumed the Salado to be halite and the Culebra to have anhydrite material parameters.

Maximum *Subsidence* at the Culebra was estimated to be 0.56 m (1.8 ft). The vertical strain was concentrated in the Salado above the repository. Vertical strain was less than 0.01 percent in units overlying the Salado and was close to zero in the Culebra (Westinghouse 1994, Figure 3-40). The maximum horizontal displacement in the Culebra was estimated to be 0.02 m (0.08 ft), with a maximum tensile horizontal strain of 0.007 percent. The DOE (Westinghouse 1994, 4-1 to 4-2) concluded that the induced strains in the Culebra will be uniformly distributed because no large-scale faults or discontinuities are present in the vicinity of the WIPP. Furthermore, strains of this magnitude would not be expected to cause extensive fracturing.

At the WIPP site, the Culebra hydraulic conductivity varies spatially over approximately four orders of magnitude, from 1×10^{-8} m (3.2×10^{-8} ft) per second (0.4 m (1.3 ft) per year) to 1×10^{-5} m (3.2×10^{-5} ft) per second (Appendix PA, Attachment TFIELD). Where transmissive horizontal fractures exist, hydraulic conductivity in the Culebra is dominated by flow through the fractures. An induced tensile vertical strain may result in an increase in fracture aperture and corresponding increases in hydraulic conductivity. The magnitude of increase in hydraulic conductivity can be estimated by approximating the hydrological behavior of the Culebra with a simple conceptual model of fluid flow through a series of parallel fractures with uniform properties. A conservative estimate of the change in hydraulic conductivity can be made by assuming that all the vertical strain is translated to fracture opening (and none to rock expansion). This method for evaluating changes in hydraulic conductivity is similar to that used by the EPA in estimating the effects of subsidence caused by potash mining (Peake 1996; EPA 1996b).

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

$$K = \frac{w^3 \rho g N}{12 \mu 2}, \tag{1}$$

where w is the fracture aperture, ρ is the fluid density (taken to be 1,000 kg/m³), g is the acceleration due to gravity (9.79 m (32 ft) per second squared), μ is the fluid viscosity (taken as 0.001 pascal seconds), D is the effective Culebra thickness (7.7 m (26.3 ft)), and N is the number of fractures. For 10 fractures with a fracture aperture, w, of 6×10^{-5} m (2×10^{-4} ft), the Culebra hydraulic conductivity, K, is approximately 7 m per year (2×10^{-7} m (6.5×10^{-7} ft) per second). The values of the parameters used in this calculation are within the range of those expected for the Culebra at the WIPP site (Appendix PA, Attachment TFIELD).

The amount of opening of each fracture as a result of subsidence-induced tensile vertical strain, ε, (assuming rigid rock) is $D\varepsilon/N$ meters. Thus, for a vertical strain of 0.0001, the fracture aperture, w, becomes approximately 1.4×10^{-4} m. The Culebra hydraulic conductivity, K, then increases to approximately 85 m (279 ft) per year (2.7×10^{-6} m (8.9×10^{-6} ft) per second). Thus, on the basis of a conservative estimate of vertical strain, the hydraulic conductivity of the Culebra may increase by an order of magnitude. In the PA calculations, multiple realizations of the Culebra transmissivity field are generated as a means of accounting for spatial variability and uncertainty (Appendix TFIELD). A change in hydraulic conductivity of one order of magnitude through vertical strain is within the range of uncertainty incorporated in the Culebra transmissivity field through these multiple realizations. Thus, changes in the horizontal component of Culebra hydraulic conductivity resulting from repository-induced subsidence have been eliminated from PA calculations on the basis of low consequence.

A similar calculation can be performed to estimate the change in vertical hydraulic conductivity in the Culebra as a result of a horizontal strain of 0.00007 m/m (Westinghouse 1994, p. 3-20). Assuming this strain to be distributed over about 1,000 fractures (neglecting rock expansion), with zero initial aperture, in a lateral extent of the Culebra of about 800 m (2,625 ft) (Westinghouse 1994, Figure 3-39), then the subsidence-induced fracture aperture is approximately 6×10^{-5} m (1.9 $\times 10^{-4}$ ft). Using the values for ρ, g, and μ, above, the vertical hydraulic conductivity of the Culebra can then be calculated, through an equation similar to above, to be 7 m (23 ft) per year (2×10^{-7} m (6.5×10^{-7} ft) per second). Thus, vertical hydraulic conductivity in the Culebra may be created as a result of repository-induced *Subsidence*, although this is expected to be insignificant.

In summary, as a result of observations of *Subsidence* associated with potash mines in the vicinity of the WIPP, the potential for *Subsidence* to create fluid flow paths between the repository and units overlying the Salado has been eliminated from PA calculations on the basis of low probability. The effects of repository-induced *Subsidence* on hydraulic conductivity in the Culebra have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.2.1.4 FEP Number(s):   **H25 and H26**
        FEP Title(s):   ***Oil and Gas Extraction (H25)***
                                    Groundwater Extraction (H26)

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.*

Summary of New Information
The screening argument for this FEP has been updated with new information relating to a new water well used for ranching purposes near WIPP. No change to the screening decisions is merited.

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.

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 of the CCA) (DOE 1996a). 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. Additionally, a new water well was drilled in 2007 at the SNL-14 wellpad to provide livestock water for the Mills ranch. This well is approximately 3,000 feet (0.9 km) from the WIPP site boundary.

If contaminated water intersects a well while it is producing, then contaminants could be pumped to the surface. Consistent with the containment requirements in 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 of the CCA (DOE 1996a), 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 CCA Chapter 6.0, Section 6.4.6.6). Retardation of any radionuclides that enter the Dewey Lake will be such that no radionuclides will migrate through the Dewey Lake to the accessible environment within the 10,000-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 (1996a) showed that such a well pumping at about 0.5 g (1.9 L) per minute for 10,000 years will induce a hydraulic head gradient across the controlled area of about 4×10^{-5}. The hydraulic head gradient across the controlled area currently ranges from between 0.001 to 0.007. Therefore, pumping from the Engle Well will have only minor effects on the hydraulic head gradient within the controlled area even if pumping were to continue for 10,000 years. Thus, the effects of HCN *Groundwater Extraction* outside the controlled area have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

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

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.

2.2.1.5   **FEP Number(s):**   **H27, H28 and H29**
         FEP Title(s):   **Liquid Waste Disposal (outside boundary [OB]) (H27)**
                      Enhanced Oil and Gas Production – OB (H28)
                      Hydrocarbon Storage – OB (H29)

Screening Decision: **SO-C (HCN)**
                                      SO-C (Future)

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

Summary of New Information
These FEPs are specific to activities outside the WIPP boundary, although past descriptions have sometimes confused these activities with possible events occurring inside the WIPP boundary (IB). 40 CFR 194.33(d) excludes activities subsequent to drilling the borehole from further consideration in PA. It has historically been understood that this exclusion implicitly applies to activities within the WIPP boundary, and not those OB. Therefore, three new FEPs have been created to address analogous IB activities (see FEPs H60, Liquid Disposal - IB; H61 Enhanced Oil and Gas Production – IB; and H62 Hydrocarbon Storage – IB).

Recent monitoring activities have identified a salt water disposal well that had hardware failure resulting in migration of the injected fluid away from the wellbore in a shallow freshwater producing zone. This leak may have persisted up to 22 months, based on inspection and test records on file with the New Mexico Oil Conservation Division. Once the failure was identified, the well was repaired and returned to service. Details of this event are discussed in Hall et al. (2008).

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). Conservative assumptions used by Stoelzel and Swift include a leaking well that persists for many years (150) with pressures above maximum allowable permitted pressures in the area. Therefore, current modeling conservatively bounds the effects of the recent injection well failure mentioned above. Neither liquid waste disposal nor waterflooding conducted in wells outside the controlled area have the potential to affect the disposal system in any significant way.

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.

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 (CO2) 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 CO_2 miscible flooding, have been implemented with limited success in the Delaware Basin, but CO_2 miscible flooding is not an attractive recovery method for reservoirs near WIPP (Melzer 2008). Even if CO_2 flooding were to occur the effects (if any) would be very similar to those associated with waterflooding.

Reinjection of gas for storage currently takes place at one location in the Delaware Basin in a depleted gas field in the Morrow Formation at the Washington Ranch near Carlsbad Caverns (Burton et al. 1993, pp. 66-67; 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.

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

- There are significant differences between the geology and lithology in the vicinity of the disposal system and that of the Vacuum and Rhodes-Yates Fields. The WIPP is located in the Delaware Basin in a fore-reef environment, where a thick zone of anhydrite and halite (the Castile) exists. In the vicinity of the WIPP, oil is produced from the Brushy Canyon Formation at depths greater than 2100 m (7,000 ft). By contrast, the Castile is not present at either the Vacuum or the Rhodes-Yates Field, which lie outside the Delaware Basin. Oil

production at the Vacuum Field is from the San Andres and Grayburg Formations at depths of approximately 1400 m (4,500 ft), and oil production at the Rhodes-Yates Field is from the Yates and Seven Rivers Formations at depths of approximately 900 m (3,000 ft). Waterflooding at the Rhodes-Yates Field involves injection into a zone only 60 m (200 ft) below the Salado. There are more potential thief zones below the Salado near the WIPP than at the Rhodes-Yates or Vacuum Fields; the Salado in the vicinity of the WIPP is therefore less likely to receive any fluid that leaks from an injection borehole. Additionally, the oil pools in the vicinity of the WIPP are characterized by channel sands with thin net pay zones, low permeabilities, high irreducible water saturations, and high residual oil saturations. Therefore, waterflooding of oil fields in the vicinity of the WIPP on the scale of that undertaken in the Vacuum or the Rhodes-Yates Field is unlikely.

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

- Recent improvements in well completion practices and reservoir operations management have reduced the occurrences of leakages from injection wells. For example, injection pressures during waterflooding are typically kept below about 23×10^3 pascals per meter to avoid fracture initiation. Also, wells are currently completed using cemented and perforated casing, rather than the open-hole completions used in the early Rhodes-Yates wells. A recent report (Hall et al. 2008) concludes that injection well operations near WIPP have a low failure rate, and that failures, are remedied as soon as possible after identification.

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 CCA Chapter 6.0, Section 6.4.7.2). Saltwater disposal into the Upper Bell Canyon was simulated, with annular leakage through the Salado. A total of approximately 7×10^5 m³ (2.47×10^7 ft³) of brine was injected through the boreholes during a 50-year simulated disposal period. In this time, approximately 50 m³ (1765.5 ft³) of brine entered the anhydrite interval at the horizon of the waste disposal region. For the next 200 years the boreholes were assumed to be abandoned (with open-

hole permeabilities of 1×10^{-9} m^2 (4×10^{-8} in.)). Cement plugs (of permeability 1×10^{-17} m^2 (4×10^{-16} in.)) were assumed to be placed at the injection interval and at the top of the Salado. Subsequently, the boreholes were prescribed the permeability of silty sand (see CCA Chapter 6.0, 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.

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 CCA Chapter 2.0, 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

$$\overline{v} = -\frac{k}{\mu}[\nabla p - \rho \overline{g}], \tag{2}$$

where

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

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

$$\overline{v} = -K\left[\nabla H_f + \frac{\Delta \rho}{\rho_f}\nabla E\right], \tag{3}$$

where

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

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

$$DFR = \frac{\Delta \rho |\nabla E|}{\rho_f |\nabla H_f|}$$

(4)

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.

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.

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 Disposal* (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.

2.2.1.6 **FEP Number**   **H58**
         FEP Title: *Solution Mining for Potash*

Screening Decision: **SO-R (HCN)**
                                 SO-R (future)

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

Summary of New Information
Plans for the development of a potash solution mine in the region continue, although the solution process has not begun; the project remains in the permitting and planning stage. The project lies outside the Delaware Basin, but DOE maintains communication with the operator, Intrepid Potash New Mexico LLC to monitor project status.

Screening Argument
Currently, no *Solution Mining for Potash* occurs in the Carlsbad Potash District (CPD). The prospect of using solution-mining techniques for extracting potash has been identified in the region,

but has not been implemented. A pilot plant for secondary solution mining of sylvite in the Clayton Basin, just north of the Delaware Basin was permitted, and concept planning took place during the mid-1990s and was noted by the EPA in their Response to Comments to the CCA (EPA 1998b). Continued progress has been made towards initiating this project, but as of the submittal of this recertification application, the project has not begun. The project intends to solution mine sylvite from retired underground mine workings at the old Potash Corporation of America lease. To date, discharge permits have been filed with the State of New Mexico, but are pending. Therefore, it is premature to consider this an operational solution mining activity. More importantly, the proposed site is outside the Delaware Basin.

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

Communiqués with IMC Global (Heyn 1997, Prichard 2003), indicate that rock temperature is critical to the success of a solution-mining endeavor. IMC Global's solution mines in Michigan and Saskatchewan are at depths around 914 m (3,000 ft) or greater, at which rock temperatures are higher. The ore zones at WIPP are shallow, at depths of 457 to 549 m (1500 to 1800 ft), with fairly cool rock temperatures. David Prichard of IMC Global states that solution mining is energy intensive and the cool temperature of the rock would add to the energy costs. In addition, variable concentrations of confounding minerals (such as kainite and leonite) will cause problems with the brine chemistry.

Typically, solution mining is used for potash:

- when deposits are at depths in excess of 914 m (3000 ft) and rock temperatures are high or are geologically too complex to mine profitably using conventional underground mining techniques;

- to recover the potash pillars at the end of a mine's life; or

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

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

The impact on the WIPP of neighboring potash mines was examined in detail by D'Appolonia (1982) and evaluated the possible effects of *Solution Mining for Potash* or other evaporite minerals. According to D'Appolonia (1982), and in agreement with Heyn (1997) of IMC Global

Inc, solution mining of langbeinite is not technically feasible because the ore is less soluble than the surrounding evaporite minerals. Solution mining of sylvite was unsuccessfully attempted in the past by the Potash Company of America and Continental Potash, both ore bodies currently owned by Mississippi Chemical. Failure of solution mining was attributed to low ore grade, thinness of the ore beds, and problems with heating and pumping injection water. Unavailability of water in the area would also impede implementation of this technique. For these reasons, solution mining is not currently used in the Carlsbad Potash District.

Serious technical and economic obstacles exist that render *Solution Mining for Potash* very unlikely in the vicinity of the WIPP. Expectedly, no operational example of this technology exists in the CPD; that is, *Solution Mining for Potash* in not considered a current practice in the area. For this reason, consideration of solution mining on the disposal system in the future may be excluded on regulatory grounds. For example, the EPA stated in their Response to Comments, Section 8, Issue GG (EPA 1998b):

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

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

2.2.1.7 FEP Number: **H59**
   FEP Title: ***Solution Mining for Other Resources***

Screening Decision: **SO-C (HCN)**
   SO-C (future)

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

Summary of New Information
Brine well information provided in Table 2-2 has been updated based on new information from the Delaware Basin Monitoring Program (DOE 2007a).

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

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

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

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

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

In doublet operations, a pair of boreholes are drilled, cased and cemented into the upper part of the halite unit. The base of the production well is set some feet below the base of the injection well. In the absence of natural fractures or other connections between the boreholes, hydrofracturing is used to induce fractures around the injection well. During operation, fresh water is pumped down the injection well. This initially dissolves halite from the walls of the fractures and the resulting brine is then pumped from the production well. After a period of operation a cavity develops between the

boreholes as the halite between fractures is removed. Because of its lower density, fresh water injected into this cavity will rise to the top and dissolve halite from the roof of the cavity. As the brine density increases it sinks within the cavern and saturated brine is extracted from the production well.

Current Brine Wells within the Delaware Basin

Brine wells are classified as Class II injection wells. In the Delaware Basin, the process includes injecting fresh water into a salt formation to create a saturated brine solution which is then extracted and utilized as a drilling agent. These wells are tracked by the Delaware Basin Drilling Surveillance Program on a continuing basis. Supplemental information provided to the EPA in 1997 showed 11 brine wells in the Delaware Basin. Since that time, additional information has shown that there are 16 brine wells within the Delaware basin, of which four are plugged and abandoned. This results in 12 currently active brine wells. Table 2-2 provides information on these wells.

Table 2-2. Delaware Basin Brine Well Status

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

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

Solution Mining for Other Minerals

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

Solution Mining for Gas Storage

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

Solution Mining for Disposal

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

Effects of Solution Mining
Subsidence

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

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

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

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

m (460 ft) and an estimated average cavity growth rate of 7.9×10^3 m^3 per year (2.8×10^5 ft^3 per year), shows that a further 15 years of operation is required before the cavity reaches the critical ratio.

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

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

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

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

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

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

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

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

Conclusion of Low Consequence

Brine production through solution mining takes place in the Delaware Basin, and the DOE assumes it will continue in the near future. Because of the existence of these solution operations, it is not possible to screen this activity based on the provisions of 40 CFR 194.25(a). However, despite oil and gas exploration and production taking place in the vicinity of the WIPP site, the nearest operating solution mine is more than 32 km (20 mi) from the WIPP site. These locations are too far from the WIPP site for any changes in hydrogeology or geochemistry, from subsidence or fresh water or brine leakage, to affect the performance of the disposal system. Thus, the effects of historical, current, near-future, and future *Solution Mining for Other Resources* in the Delaware Basin can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.2.2 Information from the EPA CARDs and TSDs

This section will evaluate information from EPA documents associated with their review of the CRA-2004 and the DOE's demonstration of compliance with 40 CFR 194.32, Scope of Performance Assessments. Section 2.2.2 of EPA's TSD for Section 194.25, 194.32, and 194.33 identifies an inconsistencies in the screening arguments of FEPs H21, H22, and H41 (EPA 2006c). Therefore, the following change has been made to address these inconsistencies:

2.2.2.1 FEP Number: H21
FEP Title: *Drilling Fluid Flow*

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.

Summary of New Information

The screening argument for this FEP has been revised slightly to remove confusion and inconsistency as suggested by the EPA in their Technical Support Document for Section 194.25, 194.32, and 194.33 (EPA 2006d).

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.

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.

Future Human EPs
For the future, drill holes may intersect the waste disposal region and their effects could be more profound. Thus, the possibility of a future borehole penetrating a waste panel, so that *Drilling Fluid Flow* and, potentially, *Blowout*, results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in PA calculations.

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

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

2.2.2.2 FEP Number: H22
FEP Title: *Drilling Fluid Loss*

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.*

Summary of New Information
The screening argument for this FEP has been revised slightly to remove confusion and inconsistency as suggested by the EPA in their TSD for Section 194.25, 194.32, and 194.33 (EPA 2006c).

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

In evaluating the potential consequences of **Drilling Fluid Loss** to a waste panel in the future, two types of drilling events need to be considered – those that intercept pressurized fluid in underlying formations such as the Castile (defined in CCA Section 6.3.2.2 as E1 events) (DOE 1996a), and those that do not (E2 events). A possible hydrological effect would be to make a greater volume of brine available for gas generation processes and thereby increase gas volumes at particular times in the future. For either type of drilling event, on the basis of current drilling practices, the driller is assumed to pass through the repository rapidly. Relatively small amounts of drilling fluid loss 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) (CCA 1996a). 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.

The consequences of *Drilling Fluid Loss* into waste panels in the future are accounted for in PA calculations for E2 events.

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.

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.

2.2.2.3   **FEP Number:**   **H41**
          FEP Title: ***Surface Disruptions***

Screening Decision: **UP** (HCN)
                               SO-C (Future)

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

Summary of New Information
The screening decision has been changed from SO-R to SO-C. The EPA's Technical Support Document for Features, Events, and Processes (EPA 2006c) identified an inconsistency between the

screening decision and the screening rationale. After review, it has been determined that SO-C is the correct screening decision and the previous classification of SO-R is not correct.

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

Historical, Current, and Near-Future Human EPs
Most surface activities have no potential to affect the disposal system and are, therefore, screened out on the basis of low consequence (e.g., H17 Archaeological Excavations and H53, Arable Farming). However, the effects of activities capable of altering the disposal system (disposal of potash effluent) are included in the modeling of current conditions (i.e., heads) at and around the site. Discussion regarding these anthropogenic effects is found in Section 2.2.1.4.2.2 of the CRA-2004.

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

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

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

2.2.3 Inventory Data

This section presents those FEPs that have changed as a result of the inventory used for the CRA-2009 (Leigh et al. 2005a).

2.2.3.1 FEP Number: **W2 and W3**
FEP Title: **Waste Inventory (W2)**
Heterogeneity of Waste Forms (W3)

Screening Decision: **UP (W2)**
DP (W3)

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

Summary of New Information
The waste inventory used for the CRA-2009 PA calculations is the same as used for the Performance Assessment Baseline Calculation (PABC) (see Clayton 2008 and Leigh et al. 2005a). Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the in previous performance assessments, however the screening decision has not changed.

Screening Argument
Waste characteristics, comprising the **Waste Inventory** and the **Heterogeneity of Waste Forms**, are described in Attachment BIR of the CRA-2004. The waste inventory is accounted for in PA calculations in deriving the dissolved actinide source term (see Appendix SOTERM) and gas generation rates (see Section 2.3 of Leigh et al. 2005b). The distribution of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste within the repository leads to room scale heterogeneity of the waste forms, which is accounted for in PA calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion (Appendix PA, Section PA-3.8).

2.2.3.2 FEP Number: **W4**
FEP Title: ***Container Form***

Screening Decision: **SO-C - Beneficial**

*The **Container Form** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
Some inventory information has been updated for this CRA since the CRA-2004. As described in Section 24 of this CRA, inventory information is the same as that used for the PABC. This inventory is described in Leigh et al., (2005b). This inventory is slightly different than that used for the CRA-2004, although no changes affect the container form. As such, changes represented in the

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inventory used for this application do not affect this FEP or its screening decision. The physical form of the containers is conservatively ignored in performance calculations.

Screening Argument
The *Container Form* has been eliminated from PA calculations on the basis of its beneficial effect on retarding radionuclide release. The PA assumes instantaneous container failure and waste dissolution consistent with the source-term model; even though WIPP performance calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 years (see Helton et al. 1998). For all undisturbed cases, at least 30 percent of the steels will remain uncorroded at the end of 10,000 years. All these undegraded container materials will (1) prevent the contact between brine and radionuclides; (2) decrease the rate and extent of radionuclide transport due to high tortuosity along the flow pathways and, as a result, increase opportunities for metallic Fe and corrosion products to beneficially reduce radionuclides to lower oxidation states. Therefore, the container form can be eliminated on the basis of its beneficial effect on retarding radionuclide transport. In CCA Appendix WCL, a minimum quantity of metallic Fe was specified to ensure sufficient reactants to reduce radionuclides to lower and less soluble oxidation states. This requirement is met as long as there are no substantial changes in container materials. The inventory used for the CRA-2009 indicates that the density of steel in container materials currently reported by the sites has an average value of $170 \ kg/m^3$. This is the same value used for the CRA-2004, but represents an increase over what was reported for the CCA (139 to 230 kg/m^3) (8.6 to 14.3 lb/ft^3). Therefore, the current inventory estimates indicate that there is a sufficient quantity of metallic iron to ensure reduction of radionuclides to lower and less soluble oxidation states.

2.2.3.3   FEP Number: W13
         FEP Title: *Heat From Radioactive Decay*

Screening Decision: SO-C

The effects of temperature increases as a result of radioactive decay have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Summary of New Information
The radionuclide inventory used for the CRA-2009 PA calculations (Leigh et al. 2005a) is lower than previously estimated for the CCA. Thus, all CRA radioactive decay heat screening arguments are bounded by the previous CCA screening arguments.

Screening Argument
Radioactive decay of the waste emplaced in the repository will generate heat. The importance of *Heat from Radioactive Decay* depends on the effects that the induced temperature changes would have on mechanics (W29 - W31), fluid flow (W40 and W41), and geochemical processes (W44 through W75). For example, extreme temperature increases could result in thermally induced fracturing, regional uplift, or thermally driven flow of gas and brine in the vicinity of the repository.

The design basis for the WIPP requires that the thermal loading does not exceed 10 kW per acre. Transportation restrictions also require that the thermal power generated by waste in an RH-TRU container shall not exceed 300 watts (NRC 2002).

The DOE has conducted numerous studies related to *Heat from Radioactive Decay*. The following presents a brief summary of these past analyses. First, a numerical study to calculate induced temperature distributions and regional uplift is reported in DOE (1980 pp. 9-149 to 9-150). This study involved estimation of the thermal power of CH-TRU waste containers. The DOE (1980 pp. 9-149) analysis assumed the following:

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

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

- Approximately 3.7×10^5 m^3 (1.3×10^7 ft^3) of CH-TRU waste are distributed within a repository enclosing an area of 7.3×10^5 m^2 (7.9×10^6 ft^2). This is a conservative assumption in terms of quantity and density of waste within the repository, because the maximum capacity of the WIPP is 1.756×10^5 m^3 (6.2×10^6 ft^3) for all waste (as specified by the Land Withdrawal Act [LWA]) to be placed in an enclosed area of approximately 5.1×10^5 m^2 (16 mi^2).

- Half of the CH-TRU waste volume is placed in drums and half in boxes so that the repository will contain approximately 900,000 drums and 900,000 boxes. Thus, a calculated thermal power of 0.7 watts per square meter (2.8 kW/acre) of heat is generated by the CH-TRU waste.

- Insufficient RH-TRU waste would be emplaced in the repository to influence the total thermal load.

Under these assumptions, Thorne and Rudeen (1981) estimated the long-term temperature response of the disposal system to waste emplacement. Calculations assumed a uniform initial power density of 2.8 kW/acre (0.7 W/m^2) which decreases over time. Thorne and Rudeen (1981) attributed this thermal load to RH-TRU waste, but the DOE (1980), more appropriately, attributed this thermal load to CH-TRU waste based on the assumptions listed above. Thorne and Rudeen (1981) estimated the maximum rise in temperature at the center of a repository to be 1.6°C (2.9°F) at 80 years after waste emplacement.

More recently, Sanchez and Trellue (1996) estimated the maximum thermal power of an RH-TRU waste container. The Sanchez and Trellue (1996) analysis involved inverse shielding calculations to evaluate the thermal power of an RH-TRU container corresponding to the maximum permissible surface dose of 1000 rem per hour. The following calculational steps were taken in the Sanchez and Trellue (1996) analysis:

- Calculate the absorbed dose rate for gamma radiation corresponding to the maximum surface dose equivalent rate of 1000 rem per hour. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because the maximum

dose rate from neutrons is 270 millirem per hour, and the corresponding neutron heating rate will be insignificant.

- Calculate the exposure rate for gamma radiation corresponding to the absorbed dose rate for gamma radiation.

- Calculate the gamma flux density at the surface of a RH-TRU container corresponding to the exposure rate for gamma radiation. Assuming the gamma energy is 1.0 megaelectron volts, the maximum allowable gamma flux density at the surface of a RH-TRU container is about 5.8×10^8 gamma rays per square centimeter per second.

- Determine the distributed gamma source strength, or gamma activity, in an RH-TRU container from the surface gamma flux density. The source is assumed to be shielded such that the gamma flux is attenuated by the container and by absorbing material in the container. The level of shielding depends on the matrix density. Scattering of the gamma flux, with loss of energy, is also accounted for in this calculation through inclusion of a gamma buildup factor. The distributed gamma source strength is determined assuming a uniform source in a right cylindrical container. The maximum total gamma source (gamma curies) is then calculated for a RH-TRU container containing 0.89 m^3 (31.4 ft^3) of waste. For the waste of greatest expected density (about 6,000 kg/m^3 (360 lb/ft^3), the gamma source is about 2×10^4 Ci/m^3 (566 Ci/ft^3).

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

- Calculate the thermal load of a RH-TRU container from the total curie load. The ratio of thermal load to curie load was estimated through examination of the radionuclide inventory presented in CCA Appendix BIR. The thermal load and the total curie load for each radionuclide listed in the WIPP inventory were summed. Based on these summed loads the ratio of thermal load to curie load of RH-TRU waste was calculated to be about 0.0037 watts per curie. For a gamma source of 2×10^4 Ci/m^3 (566 Ci/ft^3), the maximum permissible thermal load of a RH-TRU container is about 70 W/m^3 (2 W/ft^3). Thus, the maximum thermal load of a RH-TRU container is about 60 W, and the transportation limit of 300 W will not be achieved.

Note that Sanchez and Trellue (1996) calculated the average thermal load for a RH-TRU container to be less than 1 W. Also, the total RH-TRU heat load is less than 10 percent of the total heat load in the WIPP. Thus, the total thermal load of the RH-TRU waste will not significantly affect the average rise in temperature in the repository resulting from decay of CH-TRU waste.

Temperature increases will be greater at locations where the thermal power of an RH-TRU container is 60 W, if any such containers are emplaced. Sanchez and Trellue (1996) estimated the temperature increase at the surface of a 60 W RH-TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 W/m^3 (2 W/ft^3). These conditions represent conservative assumptions because the thermal load will

decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3°C (5.4°F).

In summary, previous analyses have shown that the average temperature increase in the WIPP repository, due to radioactive decay of the emplaced CH- and RH-TRU waste, will be less than 2°C (3.6°F). Temperature increases of about 3°C (5.4°F) may occur in the vicinity of RH-TRU containers with the highest allowable thermal load of about 60 watts (based on the maximum allowable surface dose equivalent for RH-TRU containers). Potential heat generation from nuclear criticality is discussed in W14 and exothermic reactions and the effects of repository temperature changes on mechanics are discussed in the set of FEPs grouped as W29, W30, W31, W72, and W73. These FEPs have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Additionally, WIPP transportation restrictions and WIPP design basis loading configurations do not allow the thermal load of the WIPP to exceed 10 kW/acre (NRC 2002). Transportation requirements restrict the thermal load from RH-TRU waste containers to no more than 300 watts per container (NRC 2002). However, the limit on the surface dose equivalent rate of the RH-TRU containers (1,000 rem/hr) is more restrictive and equates to a thermal load of only about 60 watts per container. Based on the thermal loads permitted, the maximum temperature rise in the repository from radioactive decay heat should be less than 2°C (3.6°F).

The previous FEPs screening arguments for the CCA used a bounding radioactivity heat load of 0.5 watts/drum for the CH-TRU waste containers. With a total CH-TRU volume of 168,500 m³ (~5,950,000 ft³) this corresponds to approximately 810,000 55-gallon drum equivalents with a corresponding heat load of > 400 kW used for the CCA FEPs screening arguments. From Sanchez and Trellue (1996), it can be seen that a realistic assessment of the heat load, based on radionuclide inventory data in the Transuranic Waste Baseline Inventory Report (TWBIR) is less than 100 kW. Thus, the CCA FEPs incorporate a factor of safety of at least four, and heat loads from the CRA-2009 inventory would be even less.

2.2.3.4 FEPs Number: **W14**
FEPs Title: ***Nuclear Criticality: Heat***

Screening Decision: **SO-P**

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

Summary of New Information
Appendix PA, Section PA-2.2 states that the inventory used for the CRA-2009 is based on Leigh et al. (2005b). This is the same inventory used for the CRA-2004 Performance Assessment Baseline Calculation (PABC). Leigh et al. (2005b) shows that the disposal inventory of fissile material continues to decrease below that used for the CCA (DOE 1996a). Thus, CRA-2009 criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

Screening Argument

Nuclear Criticality refers to a sustained fission reaction that may occur if fissile radionuclides reach both a sufficiently high concentration and total mass (where the latter parameter includes the influence of enrichment of the fissile radionuclides). In the subsurface, the primary effect of a nuclear reaction is the production of heat.

Nuclear criticality (near and far field) was eliminated from PA calculations for the WIPP for waste contaminated with TRU radionuclides. The probability for criticality within the repository is low (there are no mechanisms for concentrating fissile radionuclides dispersed amongst the waste). Possible mechanisms for concentration in the waste disposal region include high solubility, compaction, sorption, and precipitation. First, the maximum solubility of ^{239}Pu in the WIPP repository, the most abundant fissile radionuclide, is orders of magnitude lower than necessary to create a critical solution. The same is true for ^{235}U, the other primary fissile radionuclide. Second, the waste is assumed to be compacted by repository processes to one fourth its original volume. This compaction is still an order of magnitude too disperse (many orders of magnitude too disperse if neutron absorbers that prevent criticality (for example, ^{238}U) are included). Third, any potential sorbents in the waste would be fairly uniformly distributed throughout the waste disposal region; consequently, concentration of fissile radionuclides in localized areas through sorption is improbable. Fourth, precipitation requires significant localized changes in brine chemistry; small local variations are insufficient to separate substantial amounts of ^{239}Pu from other actinides in the waste disposal region (for example, 11 times more ^{238}U is present than ^{239}Pu).

Criticality away from the repository (following an inadvertent human intrusion) has a low probability because (1) the amount of fissile material transported from the repository is small; (2) host rock media have small porosities (insufficient for generation of sizable precipitation zone); and (3) no credible mechanism exists for the concentrating fissile material during transport (the natural tendency is for transported to be dispersed). As discussed in CRA-2004 Chapter 6.0, Section 6.4.6.2 and CRA-2004 Appendix PA, Attachment MASS Section MASS.15, the dolomite porosity consists of intergranular porosity, vugs, microscopic fractures, and macroscopic fractures. As discussed in CRA-2004 Chapter 6.0, Section 6.4.5.2, porosity in the marker beds consists of partially healed fractures that may dilate as pressure increases. Advective flow in both units occurs mostly through macroscopic fractures. Consequently, any potential deposition through precipitation or sorption is constrained by the depth to which precipitation and sorption occur away from fractures. This geometry is not favorable for fission reactions and eliminates the possibility of criticality. Thus, **Nuclear Criticality** has been eliminated from PA calculations on the basis of low probability of occurrence.

Additionally, screening arguments made in Rechard et al. (1996) are represented in greater detail in Rechard et al. (2000, 2001). A major finding among the analysis results in the screening arguments is the determination that fissile material would need to be reconcentrated by three orders of magnitude in order to be considered in a criticality scenario. Because inventory estimates reported in Leigh et al. (2005b) are below that used in previous calculations, screening analyses for nuclear criticality are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

2.2.3.5   FEP Number: W15, W16, and W17
**   FEP Title: Radiological Effects on Waste (W15)**

Radiological Effects on Containers (W16)
Radiological Effects on Seals (W17)

Screening Decision: SO-C

Radiological Effects on the Properties of the Waste, Container, and Seals have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Summary of New Information
The screening arguments for these FEPs have been updated to include references to the radionuclide inventory used for CRA-2009 PA calculations.

Screening Argument
Ionizing radiation can change the physical properties of many materials. Strong radiation fields could lead to damage of waste matrices, brittleness of the metal containers, and disruption of any crystalline structure in the seals. The low level of activity of the waste in the WIPP is unlikely to generate a strong radiation field. According to the inventory data presented in Leigh et al. (2005b), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 curies reported in the CCA to 2.48×10^6 curies in the CRA-2004 to 2.32×10^6 curies in the CRA-2009. This decrease will not change the original screening argument. Furthermore, PA calculations assume instantaneous container failure and waste dissolution according to the source-term model (see CCA Chapter 6.0, Sections 6.4.3.4, 6.4.3.5, and 6.4.3.6). Therefore, *Radiological Effects on the Properties of the Waste, Container, and Seals* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.2.3.6 FEP Number: W28
FEP Title: **Nuclear Explosions**

Screening Decision: SO-P

Nuclear Explosions have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.

Summary of New Information
This FEP has been updated by referencing the most recent inventory data.

Screening Argument
Nuclear explosions have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years. For a *Nuclear Explosions* to occur, a critical mass of Pu would have to undergo rapid compression to a high density. Even if a critical mass of Pu could form in the system, there is no mechanism for rapid compression. Inventory information used in for the CCA (DOE 1996a), the CRA-2004, and the CRA-2009 are presented in Leigh et al. (2005b). The updated inventory information for this CRA shows a reduction from previous estimates. Thus, current criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

2.2.3.7 FEP Number: W29, W30, W31, W72, and W73
         FEP Title: **Thermal Effects on Material Properties (W29)**
                              Thermally-Induced Stress Changes (W30)
                              Differing Thermal Expansion of Repository Components (W31)
                              Exothermic Reactions (W72)
                              Concrete Hydration (W73)

Screening Decision: SO-C

*The effects of **Thermally Induced Stress, Differing Thermal Expansion of Components,** and
Thermal Effects on Material Properties in the repository have been eliminated from PA
calculations on the basis of low consequence to performance of the disposal system.*

*The thermal effects of exothermic reactions, including **Concrete Hydration**, have been eliminated
from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
This FEP has been updated to include the most recent inventory information as presented in Leigh
et al. (2005b). Thermal calculations have been updated with the updated quantities of reactants and
provided below.

Screening Argument
Thermally Induced Stress could result in pathways for groundwater flow in the DRZ, in the
anhydrite layers and marker beds, and through seals, or it could enhance existing pathways.
Conversely, elevated temperatures will accelerate the rate of *Salt Creep* and mitigate fracture
development. Thermal expansion could also result in uplift of the rock and ground surface
overlying the repository, and thermal buoyancy forces could lift the waste upward in the salt rock.

The distributions of thermal stress and strain changes depend on the induced temperature field and
the *Differing Thermal Expansion of Components* of the repository, which depends on the
components' elastic properties. Potentially, *Thermal Effects on Material Properties* (such as
permeability and porosity) could affect the behavior of the repository.

Exothermic reactions (W72 and W73) in the WIPP repository include MgO hydration, MgO
carbonation, Al corrosion, and cement hydration (Bennett et al. 1996). Wang (1996) has shown that
the temperature rise by an individual reaction is proportional to $\sqrt{VM}$, where V is the maximum
rate of brine inflow into a waste panel for a reaction limited by brine inflow (or a specified
maximum reaction rate for a reaction limited by its own kinetics) and M is the quantity of the
reactant. MgO hydration, cement hydration, and Al corrosion are assumed to be limited by brine
inflow, because they all consume water and have high reaction rates. The amounts of reactants are
tabulated in Table 2-3.

Table 2-3. Changes in Inventory Quantities from the CCA to the CRA-2009

Inventory	CCA	CRA-2004	CRA-2009
MgO (tons)	85,600[a]	72,760 (because of the elimination of mini-sacks)[a]	59,385[e]
Cellulosics (tons)	5,940[b]	8,120[c]	8,907[f]
Plastics (tons)	3,740[b]	8,120[c]	10,180[f]

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Rubber (tons)	1,100[b]	1,960[c]	1,885[f]
Aluminum alloys (tons)	1,980[b]	1,960[c]	2,030[f]
Cement (tons)	8,540[b]	9,971[d]	13,888[g]

[a] U.S. DOE (2001)

[b] U.S. DOE (1996b). Only CH wastes are considered. Total volume of CH wastes is 1.1×10^5 m³. This is not scaled to WIPP disposal volume.

[c] CRA-2004 Appendix DATA, Attachment F. Only CH wastes are considered. Total volume of CH waste is 1.4×10^5 m³. This is not scaled to WIPP disposal volume.

[d] This estimate is derived from data in Leigh (2003) includes both reacted and unreacted cement. (1.2×10^7 kg $\times 1.4 \times 10^5$ / 168485 /1000 kg/ton = 9971 tons cement)

[e] This estimate is derived by assuming that Panel 1 has an MgO excess factor of 1.95, three panel equivalents have a 1.67 excess factor, and the remaining 6 panel equivalents have a 1.2 excess factor, resulting in a 1.416 projected excess factor for a full repository. The projected excess factor is then multiplied by the equivalent cellulose value of 28,098 × (40.3 / 27) (the MgO molar ratio).

[f] This value is derived using material densities reported in Leigh et al., (2005a) and total CH waste volume (1.45×10^5 m³ reported in Leigh et al., (2005a)).

[g] This value is derived from data in Leigh (2003) and Leigh et al., (2005a). ((1.2×10^7 kg) × 39/29 × (1.45×10^5) / 168485 / 1000 kg/ton = 13,888 tons cement)

Similarly, MgO carbonation, which consumes CO_2, is limited by CO_2 generation from microbial degradation. Given a biodegradation rate constant, the total CO_2 generated per year is proportional to the total quantity of biodegradable materials in the repository. Using the computational methods in Wang and Brush (1996a and 1996b), the inventory of biodegradable materials has been changed from 23,884 (8,120 + 1.7 × 8,120 + 1,960)[1] tons for the CRA-2004 to 28,098 (8,907 + 1.7 × 10,180 + 1885)[1] tons of equivalent cellulosics for the CRA-2009. This increase in biodegradable materials corresponds to a proportional increase in CO_2 generation. For MgO carbonation and microbial degradation, the calculated temperature rises have been updated for the changes in both microbial gas generation and waste inventory and are presented in Table 2-4.

Temperature rises (°C) by exothermic reactions are revised as follows:

Table 2-4. CCA and CRA Exothermic Temperature Rises

Reactant	CCA[1]	CRA-2004[1]	CRA-2009[1]
MgO hydration	< 4.5	< 4.7	< 4.2
MgO Carbonation	< 0.6	< 0.7	< 0.6
Microbial degradation	< 0.8	< 1.4	< 1.5
Aluminum corrosion	< 6.0	< 6.8	< 6.9
Cement hydration	< 2.0	< 2.5	< 3.0

[1] All values are in degrees Celsius.

CCA conditions following a drilling event show that aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (10.8°F) above ambient room temperature (about 27°C (80°F)) (Bennett et al. 1996). A temperature rise of 6°C (10.8°F) represented the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Revised maximum temperature rises by exothermic reactions for CRA-2009 are still less than 10°C (18°F) (as shown in Table 2-4). Such small temperature changes cannot affect material properties. Thus, ***Thermal Effects on Material Properties*** in the repository have

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

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

All potential sources of heat and elevated temperature have been evaluated and found not to produce high enough temperature changes to affect the repository's performance. Sources of heat within the repository include radioactive decay and exothermic chemical reactions such as backfill hydration and metal corrosion. The rates of these exothermic reactions are limited by the availability of brine in the repository. *Concrete Hydration* in the seals is a significant source of heat, but it is relatively short-lived (Loken 1994) and (Loken and Chen 1994). Energy released by the hydration of the seal concrete could raise the temperature of the concrete to approximately 53°C (127°F), and that of the surrounding salt to approximately 38°C (100°F), one week after seal emplacement. Elevated temperatures will persist for a short period of time, perhaps a few years or a few decades. The thermal stresses from these temperatures and the temperatures in the concrete itself have been calculated to be below the design compressive strength for the concrete. Thus, thermal stresses should not degrade the long-term performance of the seals. In general, the various sources of heat do not appear to be great enough to jeopardize the performance of the disposal system.

2.2.3.8 FEP Number: W33
FEP Title: *Movement of Containers*

Screening Decision: SO-C

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

Summary of New Information
The FEP description has been updated to reflect new waste inventory data.

Screening Argument
Movement of Waste Containers placed in salt may occur as a result two buoyancy mechanisms (Dawson and Tillerson 1978): (1) the density contrast between the waste container and the surrounding salt, and (2) the temperature contrast between a salt volume that includes a heat source and the surrounding unheated salt. When the density of the waste container is greater than the density of the surrounding salt, the container sinks relative to the salt; whereas when the salt density is greater than the container density, the container rises relative to the salt. Similarly, when a discrete volume of salt within a large salt mass is heated, the heat raises the temperature of the discrete volume above that of the surrounding salt thereby inducing density contrasts and buoyant forces that initiate upward flow of the heated salt volume. In a repository setting, the source of the heat may be radioactive decay of the waste itself or exothermic reactions of the backfill materials and waste constituents, e.g., MgO hydration, MgO carbonation, aluminum corrosion, cement hydration, and calcium oxide hydration.

For the CCA, the density of the compacted waste and the grain density of the halite in the Salado were assumed to be 2,000 kg/m^3 and 2,163 kg/m^3, respectively. Because this density contrast is small, the movement of containers relative to the salt was considered minimal, particularly when drag forces on the waste containers were also considered. In addition, vertical movement initiated

in response to thermally-induced density changes for high-level waste containers of a similar density to those at the WIPP were calculated to be approximately 0.35 m (1 ft) (Dawson and Tillerson 1978, p. 22). This calculated movement was considered conservative given that containers at the WIPP will generate much less heat and will, therefore, move less. As a result, container movement was eliminated from PA calculations on the basis of low consequences to the performance of the disposal system.

The calculations performed for DOE (1996a) were based on estimates of the waste inventory. However, with the initiation of waste disposal, actual waste inventory is tracked and future waste stream inventories have been refined. Based on an evaluation of these data, two factors may affect the conclusions reached in DOE (1996a) concerning container movement.

The first factor is changes in density of the waste form. According to CRA-2009 inventory data (Leigh et al., 2005b), the waste density has changed only slightly since that anticipated for the CCA (see Table 9, Leigh et al., 2005b). Some future waste streams may however be more highly compacted, perhaps having a density roughly three times greater than that assumed in the CCA, while others may be less dense. In calculations of container movement, Dawson and Tillerson (1978, p. 22) varied container density by nearly a factor of three (from 2,000 kg/m^3 (125 lb/ft^3) to 5,800 kg/m^3 (362 lb/ft^3)) and found that an individual dense container could move vertically as much as about 28 m (92 ft). Given the geologic environment of the WIPP, a container would likely encounter a dense stiff unit (such as an anhydrite stringer) that would arrest further movement far short of this upper bound; however, because of the massive thickness of the Salado salt, even a movement of 28 m (92 ft) would have little impact on performance.

The second inventory factor that could affect container movement is the composition of the waste (and chemical buffer) relative to its heat production. Radioactive decay, nuclear criticality, and exothermic reactions are three possible sources of heat in the WIPP repository. According to Leigh et al., (2005b), the TRU radionuclide inventory has decrease from 3.44×10^6 curies reported in the CCA to 2.48×10^6 curies in the CRA-2004 to 2.32×10^6 curies in the CRA-2009. Such a small change will not result in a significant deviation from the possible temperature rise predicted in the CCA. Additionally, and as shown in Section SCR.6.3.4 (FEPs W72 and W73), temperature rises from exothermic reactions are quite small (see Table 2-4). Note that the revised maximum temperature rises by exothermic reactions are still less than 10°C (18°F).

Based on the small differences between the temperature and density assumed in the CCA compared to those determined using new inventory data (Leigh et al. 2005b), the conclusion about the importance of container movement reported in the CCA will not be affected, even when more highly compacted future waste streams are considered. Also, the effects of the revised maximum temperature rise and higher density future waste streams on container movement are competing factors (high density waste will sink, whereas the higher temperature waste-salt volume will rise) that may result in even less movement. Therefore, *Movement of Waste Containers* has been eliminated from PA calculations on the basis of low consequence.

2.2.3.9 **FEP Number:** **W44, W45, and W48**
FEP Titles: **Degradation of Organic Material (W44)**
Effects of Temperature on Microbial Gas Generation (W45)
Effects of Biofilms on Microbial Gas Generation (W48)

Screening Decision: UP

*Microbial gas generation from **Degradation of Organic Material** is accounted for in PA calculations, and the **Effects of Temperature and Biofilm Formation on Microbial Gas Generation** are incorporated in the gas generation rates used.*

Summary of New Information
These FEPs have been updated to be consistent with the latest inventory information.

Screening Argument
Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO_2, but also nitrogen oxide, nitrogen, hydrogen sulfide, hydrogen, and methane. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. Microbial gas generation from *Degradation of Organic Material* is accounted for in PA calculations.

The following subsections discuss the effects of temperature, pressure, radiation, and biofilms on gas production rates via their control of microbial gas generation processes.

Effects of Temperature on Microbial Gas Generation
Calculations and experimental studies of induced temperature distributions within the repository have been undertaken and are described in FEPs W29, W30, and W31. Numerical analysis suggests that the average temperature increase in the WIPP repository caused by radioactive decay of the emplaced CH- and RH-TRU waste is likely to be less than 3°C (5.4°F) (FEP W13).

Temperature increases resulting from Exothermic Reactions are discussed in FEPs W72 and W73. Potentially the most significant Exothermic Reactions are Concrete Hydration, backfill hydration, and aluminum corrosion. Hydration of the seal concrete could raise the temperature of the concrete to approximately 53°C (127°F) and that of the surrounding salt to approximately 38°C (100°F) one week after seal emplacement (W73).

As discussed in FEPs W72 and W73, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 4.2°C (7.6°F), resulting from *Brine Inflow* following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature rise of about 6.9°C (12.4°F) (see W72). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 10°C

(18°F) represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

Relatively few data exist on the *Effects of Temperature on Microbial Gas Generation* under expected WIPP conditions. Molecke (1979, p. 4) summarized microbial gas generation rates observed during a range of experiments. Increases in temperature from ambient up to 40°C (104°F) or 50°C (122°F) were reported to increase gas production, mainly via the degradation of cellulosic waste under either aerobic or anaerobic conditions (Molecke 1979, p. 7). Above 70°C (158°F), however, gas generation rates were generally observed to decrease. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates, representing likely states within the repository. Gas generation rates were presented as ranges with upper and lower bounds as estimates of uncertainty (Molecke 1979, p. 7). Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). These experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. These experiments were carried out at a reference temperature of 30°C (86°F), based on the average temperature expected in the repository. Gas generation rates used in the PA calculations are described in CRA-2009 Appendix PA, Section PA-4.2.5. The effects of temperature on microbial gas generation are implicitly incorporated in the gas generation rates used.

Effects of Biofilms on Microbial Gas Generation
The location of microbial activity within the repository is likely to be controlled by the availability of substrates and nutrients. Biofilms may develop on surfaces where nutrients are concentrated. They consist of one or more layers of cells with extracellular polymeric material and serve to maintain an optimum environment for growth. Within such a biofilm ecosystem, nutrient retention and recycling maximize microbe numbers on the surface (see, for example, Stroes-Gascoyne and West 1994, pp. 9 – 10).

Biofilms can form on almost any moist surface, but their development is likely to be restricted in porous materials. Even so, their development is possible at locations throughout the disposal system. The *Effects of Biofilms on Microbial Gas Generation* may affect disposal system performance through control of microbial population size and their effects on radionuclide transport.

Molecke (1979, p. 4) summarized microbial gas generation rates observed during a range of experimental studies. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates representing likely states within the repository. However, the effect of biofilm formation in these experiments was uncertain. Molecke (1979, p. 7), presented gas generation rates as ranges, with upper and lower bounds as estimates of uncertainty. Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). Their experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. Under the more favorable conditions for microbial growth established during the experiments, the development of populations of halophilic microbes and associated biofilms was evidenced by observation of an extracellular, carotenoid pigment, bacterioruberin, in the culture bottles (Francis and Gillow 1994, p. 59). Gas

generation rates used in the PA calculations have been derived from available experimental data and are described in Appendix PA, Section PA-4.2.5. The *Effects of Biofilms on Microbial Gas Generation* rates are implicitly incorporated in the gas generation rates.

Biofilms may also influence contaminant transport rates through their capacity to retain and thus retard both the microbes themselves and radionuclides. This effect is not accounted for in PA calculations, but is considered potentially beneficial to calculated disposal system performance. Microbial transport is discussed in FEP W87.

2.2.3.10 FEP Number: **W47**
FEP Title: ***Effects of Radiation on Microbial Gas Generation***

Screening Decision: **SO-C**

*The **Effects of Radiation on Microbial Gas Generation** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
The FEP screening argument has been updated to reflect the radionuclide inventory used for CRA-2009 calculations, although the screening decision has not changed.

Screening Argument
Radiation may slow down microbial gas generation rates, but such an effect is not taken into account in WIPP PA calculations. According to the inventory data presented in Leigh et al. (2005b), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 curies reported in the CCA to 2.48×10^6 curies in the CRA-2004 to 2.32×10^6 curies in the CRA-2009. This decrease will not affect the original screening argument.

Experiments investigating microbial gas generation rates suggest that the effects of alpha radiation from TRU waste is not likely to have significant effects on microbial activity (Barnhart et al. 1980; Francis 1985). Consequently, the *Effects of Radiation on Microbial Gas Generation* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.2.3.11 FEP Number: **W53**
FEP Title: **Radiolysis of Cellulose**

Screening Decision: **SO-C**

*Gas generation from **Radiolysis of Cellulose** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
This FEP has been updated with new inventory data related to cellulose content.

Screening Argument

Molecke (1979) compared experimental data on gas production rates caused by *Radiolysis of Cellulose* and other waste materials with gas generation rates by other processes including bacterial (microbial) waste degradation. The comparative gas generation rates reported by Molecke (1979, p. 4) are given in terms of most probable ranges, using units of moles per year per drum, for drums of 0.21 m^3 (0.27 yd^3) in volume. A most probable range of 0.005 to 0.011 moles per year per drum is reported for gas generation due to radiolysis of cellulosic material (Molecke 1979, p. 4). As a comparison, a most probable range of 0.0 to 5.5 moles per year per drum is reported for gas generation by bacterial degradation of waste.

The data reported by Molecke (1979) are consistent with more recent gas generation investigations made under the WIPP program, and indicate that radiolysis of cellulosic materials will generate significantly less gas than other gas generation processes. Gas generation from radiolysis of cellulosics therefore can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Radiolytic gas generation is controlled by the radioactivity of wastes and the waste properties. According to the new inventory presented in Leigh et al. (2005b), the overall activity for all TRU radionuclides has decreased from 3.44×10^6 curies reported in the CCA to 2.48×10^6 curies in the CRA-2004 to 2.32×10^6 curies in the CRA-2009.

Radiolytic gas generation is also limited by transportation requirements, which state that the hydrogen generated in the innermost layer of confinement must be no more than five percent over 60 days (DOE 2000). Thus, the maximum rate allowed for transportation is 0.201 m^3 per drum × five percent × 1000 L/m^3 per 60 days × 365 days per year = 61 L per drum per year, smaller than the maximum microbial gas generation rate. Note that this estimate is very conservative and the actual rates are even smaller. It is a general consensus within the international research community that the effect of radiolytic gas generation on the long-term performance of a low/intermediate level waste repository is negligible (Rodwell et al. 1999).

2.2.3.12 FEP Number: W54
        FEP Title: **Helium Gas Production**

Screening Decision: **SO-C**

Gas generation from helium production has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Summary of New Information

The updated information for the WIPP disposal inventory indicates that the expected WIPP-scale radionuclide activity (2.32 million curies of TRU isotopes) (Leigh et al. 2005b) is less than previously estimated in TWBIR Rev 3 (DOE 1996b). Thus, the *Helium Gas Production* argument for CRA-2009 is conservatively bounded by the previous CCA screening argument. The FEP screening argument and screening decision remain unchanged except for editorial changes.

Screening Argument

Helium Gas Production will occur by the reduction of α-particles (helium nuclei) emitted from the waste. The maximum amount of helium that could be produced can be calculated from the number α-particles generated during radioactive decay. The α-particles are converted to helium gas by the following reaction:

$$^4He^{2+} + 2e^- \rightarrow He(g) \tag{5}$$

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

$$R_{He} = \frac{I\left(\frac{1\,He\,atom}{\alpha - decay}\right)}{N_A} \tag{6}$$

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

I is the waste inventory, 1.5×10^{17} becquerels, assuming that 1 becquerel is equal to 1 α-decay per second, and N_A is Avogadro constant (6.022×10^{23} atoms per mole). These assumptions regarding the inventory lead to maximum estimates for helium production because some of the radionuclides will decay by beta and gamma emission.

R_{He} is approximately 5.5×10^{-7} moles per second based on an alpha-emitting inventory of 4.07 million curies. Assuming ideal gas behavior and repository conditions of 30°C (86°F) and 14.8 MPa or 146 atm (lithostatic pressure), yields approximately 1.3 liters (0.34 gallons) per year.

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

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

2.2.3.13 FEP Number: **W55**
           FEP Title: **Radioactive Gases**

Screening Decision: **SO-C**

*The formation and transport of **Radioactive Gases** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
This FEP has been updated with references to the latest inventory information.

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

Leigh et al. (2005b) indicates that a small amount of carbon-14 (2.41 curies) will be disposed in the WIPP. This amount is insignificant in comparison with the 40 CFR § 191.13 cumulative release limit for carbon-14.

Notwithstanding this comparison, consideration of transport of *Radioactive Gases* could potentially be necessary in respect of the 40 CFR § 191.15 individual protection requirements. Carbon-14 may partition into CO_2 and methane formed during microbial degradation of cellulosic and other organic wastes (for example, rubbers and plastics). However, total fugacities of CO_2 in the repository are expected to be very low because of the action of the MgO backfill which will lead to incorporation of CO_2 in solid magnesite. Similarly, interaction of CO_2 with cementitious wastes will limit CO_2 fugacities by the formation of solid calcium carbonate. Thus, because of the formation of solid carbonate phases in the repository, significant transport of carbon-14 as carbon dioxide-14 has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

Potentially significant volumes of methane may be produced during the microbial degradation of cellulosic waste. However, volumes of methane-14 will be small given the low total inventory of carbon-14, and the tendency of carbon-14 to be incorporated into solid carbonate phases in the repository. Therefore, although transport of carbon-14 could occur as methane-14, this effect has been eliminated from the current PA calculations on the basis of low consequence to the performance of the disposal system.

Radon gas will contain proportions of the alpha emitters ^{219}Rn, ^{220}Rn, and ^{222}Rn. All of these have short half-lives, but ^{222}Rn is potentially the most important because it is produced from the abundant waste isotope, ^{238}Pu, and because it has the longest half-life of the radon isotopes (≈ 4 days). ^{222}radon will exhibit secular equilibrium with its parent ^{226}Rn, which has a half-life of 1600 years. Consequently, ^{222}Rn will be produced throughout the 10,000-year regulatory time period. Conservative analysis of the potential ^{222}Rn inventory suggests activities of less than 716 curies at 10,000 years (Bennett 1996).

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

2.2.3.14 FEP Number: W89
FEP Title: Transport of Radioactive Gases

Screening Decision: SO-C

*The **Transport of Radioactive Gases** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
This FEP discussion has been updated to include recent inventory information.

Screening Argument
The production and potential ***Transport of Radioactive Gases*** are eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Transportable radioactive gases are comprised mainly of isotopes of radon and carbon-14. Radon gases are eliminated from PA because their inventory is small (<7 Ci; (Leigh et al. 2005b)) and their half-lives are short (<4 days), resulting in insignificant potential for release from the repository.

2.2.3.15 FEP Number: W93
FEP Title: Soret Effect

Screening Decision: SO-C

*The effects of thermochemical transport phenomena (the **Soret Effect**) have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information
This FEP has been updated with new thermal heat rise values for aluminum corrosion, based on the latest inventory data.

Screening Argument
According to Fick's law, the diffusion flux of a solute is proportional to the solute concentration gradient. In the presence of a temperature gradient there will also be a solute flux proportional to the temperature gradient (the ***Soret Effect***). Thus, the total solute flux, J, in a liquid phase may be expressed as

$$J = -DVC - NDVT,\tag{7}$$

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

$$N = S_T C(1-C),\tag{8}$$

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

$$\frac{\partial C}{\partial t} = \nabla \bullet \left(D\nabla C + ND\nabla T \right).\tag{9}$$

When temperature gradients exist in solutions with both light and heavy solute molecules, the heavier molecules tend to concentrate in the colder regions of the solution. Typically, large temperature gradients are required for Soret diffusion to be significant compared to Fickian diffusion.

Radioactive Decay, Nuclear Criticality, and ***Exothermic Reactions*** are three possible sources of heat in the WIPP repository. The DOE (1980) estimated that radioactive decay of CH-TRU waste will result in a maximum temperature rise at the center of the repository of 1.6°C (2.9°F) at 80 years after waste emplacement. Sanchez and Trellue (1996) have shown that the total thermal load of RH-TRU waste will not significantly affect the average temperature increase in the repository. Temperature increases of about 3°C (5.4°F) may occur at the locations of RH-TRU containers with maximum thermal power (60 W). Such temperature increases are likely to be short-lived on the time scale of the 10,000 year regulatory period because of the rapid decay of heat-producing nuclides in RH-TRU waste, such as ^{137}Cs, ^{90}Sr, ^{241}Pu, and ^{147}Pm, whose half-lives are approximately 30, 29, 14, and 3 years, respectively. Soret diffusion generated by such temperature gradients will be negligible compared to other radionuclide transport mechanisms.

Temperature increases resulting from exothermic reactions are discussed in W72. Potentially the most significant exothermic reactions are **Concrete Hydration**, backfill hydration, and **Aluminum Corrosion**. Hydration of the seal concrete could raise the temperature of the concrete to approximately 50°C (122°F) and that of the surrounding salt to approximately 38°C (100°F) one week after seal emplacement.

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

The maximum temperature rise in the disposal panels will be less than 5°C (9°F) as a consequence of MgO hydration. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. Heat generation by radioactive decay and concrete seal hydration will have decreased substantially after 100 years, and the temperatures in the disposal panels will have decreased nearly to the temperature of the undisturbed host rock.

If the repository were to be inundated following a drilling intrusion, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6.9°C (12.4°F). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6.9°C (12.4°F) represents the maximum that could occur as a result of a combination of exothermic reactions occurring simultaneously. Temperature increases of this magnitude will not result in significant Soret diffusion within the disposal system.

The limited magnitude and spatial scale of temperature gradients in the disposal system indicate that Soret diffusion will be insignificant, allowing the effects of thermochemical transport (***Soret Effect***) to be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.2.4 EPA Approved Changes

This section presents those FEPs that have changed as a result of changes to the WIPP program that EPA has approved as a result of the 40 CFR 194.4(b)(3)(i) change process.

2.2.4.1 FEP Number: W35
  FEP Title: **Mechanical Effects of Backfill**

Screening Decision: SO-C

*The **Mechanical Effects of Backfill** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

Summary of New Information

In February 2008, the EPA approved a reduction in the minimum amount of MgO to be placed in the repository (Reyes 2008). This reduction is described fully in Appendix PA, Attachment MgO. While this reduction is important to WIPP operations, it has no bearing on performance assessment calculations and the screening decisions and arguments for FEPs that are related to backfill, buffers, and barriers.

Screening Argument

The chemical conditioners or backfill added to the disposal room will act to resist creep closure. However, calculations have shown that because of the high porosity and low stiffness of the waste and the high waste to potential backfill volume, inclusion of backfill does not significantly decrease the total subsidence in the waste emplacement area or disposal room (Westinghouse 1994). In 2001, DOE eliminated MgO mini sacks from the repository reducing the total inventory from 85,600 short tons to 74,000 short tons, which reduced the potential backfill volume (EPA 2001). More recently, the required amount of MgO has been further reduced (see Appendix PA, Attachment MgO and Reyes [2008]). Therefore, the *Mechanical Effects of Backfill* have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

2.3 HOUSEKEEPING CHANGES

The following presents FEPs that have been modified for the purpose of correction or clarification.

2.3.1 Corrections

The following FEP was modified to correct errors identified during review.

2.3.1.1 FEP Number: N40
  FEP Title: **Impact of a Large Meteorite**

Screening Decision: SO-P

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

Summary of New Information

This FEP has been modified to correct errors discovered in Equations 5 and 6. As a result of these error corrections it is necessary to select an upper bound on the distribution of meteorite sizes; Ceres, the largest known asteroid, has been used to determine the upper bound.

Screening Argument

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

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

Assuming the higher estimated impact rate of 17×10^{-13} impacts per square kilometer per year for impacts leading to fracturing of sufficient extent to affect a deep repository, and assuming a repository footprint of 1.4 km × 1.6 km (0.9 mi × 1.0 mi) for the WIPP, yields a frequency of about 4×10^{-12} impacts per year for a direct hit above the repository. This impact frequency is several orders of magnitude below the screening limit of 10^{-4} per 10,000 yrs 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 the CCA, Appendix SCR, Figure SCR-1. The area within which a meteorite could impact the repository is calculated by

$$S_D = \left(L + 2 \times \frac{D}{2} \right) \times \left(W + 2 \times \frac{D}{2} \right), \tag{10}$$

where

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

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

$$F_D \propto D^{-1.8} \tag{11}$$

where

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

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

$$F_D = \int_D^{\infty} f(D) dD \tag{12}$$

and

$$f(D) = F_1 \times 1.8 \times D^{-2.8}, \tag{13}$$

where

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

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

$$N = \int_{2h}^{M} f(D) \times S_D dD, \tag{14}$$

where

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

$$N = 1.8F_1 \left[\frac{(M)^{0.2} - (2h)^{0.2}}{0.2} - LW \frac{(M)^{-1.8} - (2h)^{-1.8}}{1.8} - (L+W) \frac{(M)^{-0.8} - (2h)^{-0.8}}{0.8} \right]. \quad (15)$$

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

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

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

2.3.2   Clarification

The following FEPs have been modified to specifically relate to the area inside the WIPP boundary.

2.3.2.1   FEP Number(s):   H60, H61 and H62
FEP Title(s)   Liquid Waste Disposal (inside boundary [IB]) (H60)
Enhanced Oil and Gas Production - IB (H61)
Hydrocarbon Storage – IB (H62)

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

*The hydrological effects of HCN fluid injection (**Liquid Waste Disposal, Enhanced Oil** and **Gas Production,** and **Hydrocarbon Storage**) through boreholes inside the controlled area have been eliminated from PA calculations on regulatory grounds (40 CFR 194.25(a).* **Liquid Waste Disposal, Enhanced Oil and Gas Production,** *and* **Hydrocarbon Storage** *(within the controlled area) in the future have been eliminated from PA calculations on regulatory grounds (40 CFR 194.33(d).*

Summary of New Information
These FEPs are specific to activities inside the WIPP boundary (IB), although past discussions have sometimes confused these activities with possible events occurring outside the WIPP boundary (OB). 40 CFR 194.33(d) excludes activities subsequent to drilling the borehole from further consideration in PA. It has historically been understood that this exclusion applies only to IB activities, and not those OB. Therefore, these FEPs deal specifically with IB activities. These three

new FEPs have been created to address IB activities analogous to FEPs H27, Liquid Disposal - OB; H28 Enhanced Oil and Gas Production – OB; and H29 Hydrocarbon Storage – OB). The descriptions of the OB activities (H27 – H29) have been clarified to be specifically related to activities OB.

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

Historical, Current, and Near-Future Human EPs
Injection of fluids for the purposes of liquid disposal, enhanced oil and gas production, or hydrocarbon storage has not occurred within the WIPP boundary. Therefore, based on the future states assumption provided by 40 CFR 194.25(a), it is assumed that such activities will not occur within the near-future timeframe, which includes the period of WIPP active institutional controls. These activities are excluded from PA calculations on regulatory grounds.

Future Human EPs
The provisions of 40 CFR 194.33(d) state, *"that performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole."* Therefore, the future injection of fluids for the purposes of liquid disposal, enhanced oil and gas production, and hydrocarbon storage within the WIPP boundary have been excluded from PA calculations on regulatory grounds.

3. FEPS ASSESSMENT SUMMARY

The FEPs baseline has been re-evaluated to determine if any new information affects the screening descriptions, arguments, and decisions for WIPP FEPs. Results from FEPs assessments conducted under SP-9.4 since the CRA-2004 were reviewed to identify information that is in need of update. In addition, new information that originates outside the Sandia WIPP PA system was reviewed and compared against the FEPs baseline to identify areas of change. EPA-approved changes to the WIPP program were also incorporated, as appropriate, to the baseline. Finally, minor clarifications and improvements were made to the FEPs baseline. This review concludes with 245 FEPs in the baseline for the CRA-2009. Of these, 188 FEPs were unchanged from the CRA-2004. 35 FEPs have been updated with new information, 10 FEPs were re-titled to be more specific, 10 new FEPs were created as a result of separation from the 10 re-titled FEPs, one screening argument was changed to correct errors discovered during review, and one screening decision was changed based on review of EPA documentation (EPA 2006c). The single screening decision change does not result in a change in FEPs accounted for in PA calculations, as the FEP was previously screened out due to regulation (SO-R), and is now screened out due to consequence (SO-C). Additionally, no FEPs that were previously screened out of PA calculations have been screened in. Finally, no FEP that was screened in has been screened out of PA calculations. The 57 FEPs that have been updated or added for the CRA-2009 are listed below in Table 3-1.

Table 3-1: CRA-2009 FEPs Summary

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
N12	*Seismic Activity*	No	Updated with new seismic data.	UP
N40	*Impact of a Large Meteorite*	No	Equation errors corrected.	SO-P
H3	*Water Resources Exploration*	No	Updated with most recent monitoring information.	SO-C (HCN) SO-C (Future)
H5	*Groundwater Exploitation*	No	Updated with most recent monitoring information.	SO-C (HCN) SO-C (Future)
H21	*Drilling Fluid Flow*	No	Screening argument revised.	SO-C (HCN) DP (Future)
H22	*Drilling Fluid Loss*	No	Screening argument revised.	SO-C (HCN) DP (Future)
H25	*Oil and Gas Extraction*	No	Screening argument updated.	SO-C (HCN) SO-R (Future)
H26	*Groundwater Extraction*	No	Screening argument updated.	SO-C (HCN) SO-R (Future)
H27	*Liquid Waste Disposal (outside boundary)(OB)*	No	FEP title has been modified to show that this event or process specifically applies to activities outside the WIPP boundary. Screening argument has also been updated with new information.	SO-C (HCN) SO-C (Future)
H28	*Enhanced Oil and Gas Production – OB*	No	FEP title has been modified to show that this event or process specifically applies to activities outside the WIPP boundary. Screening argument has also been updated with new information.	SO-C (HCN) SO-C (Future)
H29	*Hydrocarbon Storage – OB*	No	FEP title has been modified to show that this event or process specifically applies to activities outside the WIPP boundary. Screening argument has also been updated with new information.	SO-C (HCN) SO-C (Future)

Table 3-1: CRA-2009 FEPs Summary

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
H60	*Liquid Waste Disposal (inside boundary)(IB)*	N/A – new FEP	This is a new FEP that is similar to H27, except that it specifically applies to activities inside the WIPP boundary.	SO-R (HCN) SO-R (Future)
H61	*Enhanced Oil and Gas Production – IB*	N/A – new FEP	This is a new FEP that is similar to H28, except that it specifically applies to activities inside the WIPP boundary.	SO-R (HCN) SO-R (Future)
H62	*Hydrocarbon Storage – IB*	N/A – new FEP	This is a new FEP that is similar to H29, except that it specifically applies to activities inside the WIPP boundary.	SO-R (HCN) SO-R (Future)
H41	*Surface Disruptions*	Yes	Screening decision changed from SO-R to SO-C to remove inconsistency with rationale.	UP (HCN) SO-C (Future)
H58	*Solution Mining for Potash*	No	Updated with information regarding solution activities and plans in the region.	SO-R (HCN) SO-R (Future)
H59	*Solution Mining for Other Resources*	No	Updated with new information regarding brine wells in the region.	SO-C (HCN) SO-C (Future)
W2	*Waste Inventory*	No	Updated to reflect the inventory data sources used for the CRA-2009 PA.	UP
W3	*Heterogeneity of Waste Forms*	No	Updated to reflect the inventory data sources used for the CRA-2009 PA	DP
W4	*Container Form*	No	Updated to reflect the inventory data sources used for the CRA-2009 PA.	SO-C – Beneficial
W6	*Shaft Seal Geometry*	No	FEP title changed to be specific to shaft seals.	UP

Table 3-1: CRA-2009 FEPs Summary

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W7	*Shaft Seal Physical Properties*	No	FEP title changed to be specific to shaft seals.	UP
W8	*Shaft Seal Chemical Composition*	No	FEP title changed to be specific to shaft seals.	Beneficial SO-C
W13	*Heat from Radioactive Decay*	No	Updated to reflect the inventory used for the CRA-2009 PA.	SO-C
W14	*Nuclear Criticality: Heat*	No	Updated to reflect the inventory used for the CRA-2009 PA.	SO-P
W15	*Radiological Effects on Waste*	No	Updated to reflect the inventory used for the CRA.	SO-C
W16	*Radiological Effects on Containers*	No	Updated to reflect the inventory used for the CRA.	SO-C
W17	*Radiological Effects on Shaft Seals*	No	FEP title changed to be specific to shaft seals; screening argument updated to reflect the inventory used for the CRA.	SO-C
W23	*Subsidence*	No	Source of subsidence monitoring data added.	SO-C
W24	*Large Scale Rock Fracturing*	No	Source of subsidence monitoring data added.	SO-P
W28	*Nuclear Explosions*	No	Updated to reflect the inventory used for the CRA-2009 PA.	SO-P
W29	*Thermal Effects on Material Properties*	No	Updated to reflect the inventory used for the CRA. New thermal calculations added.	SO-C
W30	*Thermally-Induced Stress Changes*	No	Updated to reflect the inventory used for the CRA. New thermal calculations added.	SO-C
W31	*Differing Thermal Expansion of Repository Components*	No	Updated to reflect the inventory used for the CRA. New thermal calculations added.	SO-C

Table 3-1: CRA-2009 FEPs Summary

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W72	*Exothermic Reactions*	No	Updated to reflect the inventory used for the CRA. New thermal calculations added.	SO-C
W73	*Concrete Hydration*	No	Updated to reflect the inventory used for the CRA. New thermal calculations added.	SO-C
W36	*Consolidation of Shaft Seals*	No	FEP title changed to be specific to shaft seals.	UP
W37	*Mechanical Degradation of Shaft Seals*	No	FEP title changed to be specific to shaft seals.	UP
W33	*Movement of Containers*	No	Updated to reference new inventory data.	SO-C
W35	*Mechanical Effects of Backfill*	No	Screening argument updated to reflect reduction in MgO.	SO-C
W44	*Degradation of Organic Material*	No	New thermal rise calculations referenced.	UP
W45	*Effects of Temperature on Microbial Gas Generation*	No	New thermal rise calculations referenced.	UP
W48	*Effects of Biofilms on Microbial Gas Generation*	No	New thermal rise calculations referenced.	UP
W47	*Effects of Radiation on Microbial Gas Generation*	No	Screening argument updated with new radionuclide inventory.	SO-C
W53	*Radiolysis of Cellulose*	No	Screening argument updated with new radionuclide inventory.	SO-C
W54	*Helium Gas Production*	No	Screening argument updated with new radionuclide inventory.	SO-C
W55	*Radioactive Gases*	No	Reference made to CRA-2009 inventory data.	SO-C
W74	*Chemical Degradation of Shaft Seals*	No	FEP title changed to be specific to shaft seals.	UP

Table 3-1: CRA-2009 FEPs Summary

EPA FEP I.D.	FEP Name	Screening Decision Changed	Change Summary	Screening Classification
W89	*Transport of Radioactive Gases*	No	Screening argument updated with CRA-2009 inventory data.	SO-C
W93	*Soret Effect*	No	New thermal values added for aluminum corrosion.	SO-C
W109	*Panel Closure Geometry*	N/A – new FEP.	Split from W6 to be specific to panel closures.	UP
W110	*Panel Closure Physical Properties*	N/A – new FEP	Split from W7 to be specific to panel closures.	UP
W111	*Panel Closure Chemical Composition*	N/A – new FEP	Split from W8 to be specific to panel closures.	Beneficial SO-C
W112	*Radionuclide Effects on Panel Closures*	N/A – new FEP	Split from W17 to be specific to panel closures.	SO-C
W113	*Consolidation of Panel Closures*	N/A – new FEP	Split from W36 to be specific to panel closures.	UP
W114	*Mechanical Degradation of Panel Closures*	N/A – new FEP	Split from W37 to be specific to panel closures.	UP
W115	*Chemical Degradation of Panel Closures*	N/A – new FEP	Split from W74 to be specific to panel closures.	UP

3.1   ADDITIONAL ACTIVIITES

As a result of this assessment, the following activities are required to assure that the FEPs baseline is accurately updated and documented.

1. Update the Baseline FEPs List (Kirkes 2005) with the changes listed above in Table 3.1 and place in records package 543545.

2. Modify those FEPs identified above in the baseline FEPs screening document (currently, Appendix PA, Attachment SCR of the CRA-2004). The newly modified version of Attachment SCR will be submitted as part of the CRA-2009. The updated Attachment SCR should also be placed in records package 543545.

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