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

SCR-5.2.1.10.1 Screening Decision: SO-C (HCN)
SO-C (Future)

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

SCR-5.2.1.10.2 Summary of New Information

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

SCR-5.2.1.10.3 Screening Argument

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

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

SCR-5.2.1.10.3.1.1 *Borehole-Induced Solution and Subsidence*

During the period covered by HCN FEPs, drilling within the land withdrawn for the WIPP will be controlled, and boreholes will be plugged according to existing regulations.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

Outside the area withdrawn for the WIPP, drilling has been regulated, but conditions of historical and existing boreholes are highly variable.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

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

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

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

There are three examples in the region that appear to demonstrate the process for ***Borehole-Induced Solution and Subsidence***, but the geohydrologic setting and drillhole completions differ from those at or near the WIPP.

An example of ***Borehole-Induced Solution and Subsidence*** occurred in 1980 about 160 km (100 mi) southeast of the WIPP site (outside the Delaware Basin) at the Wink Sink (Baumgardner et al. 1982; Johnson 1989); percolation of shallow groundwater through abandoned boreholes, dissolution of the Salado, and subsidence of overlying units led to a surface collapse feature 110 m (360 ft) in width and 34 m (110 ft) deep. At Wink Sink, the Salado is underlain by the Tansill, Yates, and Capitan Formations, which contain vugs and solution cavities through which brine could migrate. Also, the hydraulic head of the Santa Rosa (the uppermost aquifer) is greater than those of the deep aquifers (Tansill, Yates, and Capitan Formations), suggesting downward flow if a connection were established. A second sink (Wink Sink 2) formed in May 2002, near the earlier sink (Johnson et al., in press). Its origin is similar to the earlier sink. By February 2003, Wink Sink 2 had enlarged by surface collapse to a length of about 305 m (1000 ft) and a width of about 198 m (650 ft).

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

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

Beauheim (1986) considered the direction of natural fluid flow through boreholes in the vicinity of the WIPP. Beauheim (1986, p. 72) examined hydraulic heads measured using drill stem tests in the Bell Canyon and the Culebra at well DOE-2 and concluded that the direction of flow in a cased borehole open only to the Bell Canyon and the Culebra would be upward. Bell Canyon waters in the vicinity of the WIPP site are saline brines (e.g., Lambert 1978; Beauheim et al. 1983; Mercer et al. 1987), limiting the potential for dissolution of the overlying evaporites. However, dissolution of halite in the Castile and the Salado would increase the relative density of the fluid in an open borehole, causing a reduction in the rate of upward flow. Potentially, the direction of borehole fluid flow could reverse, but such a flow could be sustained only if sufficient driving pressure, porosity, and permeability exist for fluid to flow laterally within the Bell Canyon. A further potential sink for Salado-derived brine is the Capitan Limestone. However, the subsurface extent of the Capitan Reef is approximately 16 km (10 mi) from the WIPP at its closest point, and this unit will not provide a sink for brine derived from boreholes in the vicinity of the controlled area. A similar screening argument is made for natural deep dissolution in the vicinity of the WIPP (see N16, N17, and N18).

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

SCR-5.2.1.10.3.2 *Future Human EPs*

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see Section 6.4.7.2). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.10.3.2.1 Borehole-Induced Solution and Subsidence

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

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

Maximum dissolution, and maximum increase in borehole diameter, will occur at the top of the Salado; dissolution will decrease with depth as the percolating water becomes salt saturated. Eventually, degraded casing and concrete plug products, clays, and other materials will fill the borehole. Long-term flow through a borehole that intersects a waste panel is accounted for in disturbed performance calculations by assuming that the borehole is eventually filled by such materials, which have the properties of a silty sand (see Section 6.4.7.2). However, these calculations assume that the borehole diameter does not increase with time. Under the conditions assumed in the SCR for the CCA for an E2 drilling event at 1,000 years, about 1,000 m^3 (35,316 ft^3) would be dissolved from the lower Rustler and upper Salado Formations. If the dissolved area is approximately cylindrical or conical around the borehole, and the collapse/subsidence propagates upward as occurred in breccia pipes (e.g., Snyder and Gard 1982), the diameter of the collapsed or subsided area through the Culebra and other units would be a few tens of meters across. Changes in hydraulic parameters for this small zone should slow travel times for any hypothesized radionuclide release, as discussed for HCN occurrences. This does not change the argument for low consequence due to ***Borehole-Induced Solution and Subsidence*** for these circumstances.

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

If a borehole intercepts a waste panel and also interconnects with formations below the evaporite section, fluid flow up or down is determined by several conditions and may change over a period of time (e.g., as dissolution increases the fluid density in the borehole. Fluid flow downward is not a concern for performance, as fluid velocities in units such as the Bell Canyon are slow and should not be of concern for performance (e.g., II-G-12, 3.12.3.3.). For dissolution at the top of the evaporite section (as with boreholes considered under HCN), the process can develop a localized area around the borehole in which the hydraulic parameters for the Culebra and other units are altered. As with boreholes considered for HCN, the local change in hydraulic parameters, if it occurs along the expected flow path, would be expected to cause little change in travel time and should increase the travel time.

In summary, the effects of ***Borehole-Induced Solution and Subsidence*** around future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.11 FEP Number: H35
FEP Title: ***Borehole Induced Mineralization***

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

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

SCR-5.2.1.11.2 Summary of New Information

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

SCR-5.2.1.11.3 Screening Argument

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

Movement of fluids through abandoned boreholes could result in ***Borehole*****-Induced Geochemical Changes** in the receiving units, such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

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

SCR-5.2.1.11.3.1 *Borehole-Induced Mineralization*

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

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

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

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

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

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

SCR-5.2.1.11.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see Section 6.4.7.2). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.11.4.1 *Borehole-Induced Mineralization*

Fluid flow between hydraulically conductive horizons through a future borehole may result in changes in permeability in the affected units through mineral precipitation. However, the effects of mineral precipitation as a result of flow through a future borehole in the controlled area will be similar to the effects of mineral precipitation as a result of flow through an existing or near-future borehole (see FEP H32 and H33). Thus, ***Borehole-Induced Mineralization*** associated with flow through a future borehole has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.1.12 FEP Number: H36
FEP Title: ***Borehole-Induced Geochemical Changes***

SCR-5.2.1.12.1 Screening Decision: UP (HCN)
DP (Future)
SO-C for units other than the Culebra

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

SCR-5.2.1.12.2 Summary of New Information

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

SCR-5.2.1.12.3 Screening Argument

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

Movement of fluids through abandoned boreholes could result in ***Borehole*-Induced Geochemical Changes** in the receiving units such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

SCR-5.2.1.12.3.1 *Geochemical Effects of Borehole Flow*

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

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

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

Consistent with the screening discussion in H24, the effects of changes in sorption in the Dewey Lake inside the controlled area as a result of flow through existing and near-future abandoned boreholes have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-5.2.1.12.4 Future Human EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is complete the borehole is plugged according to current practice in the Delaware Basin (see Section 6.4.7.2). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

SCR-5.2.1.12.4.1 *Geochemical Effects of Flow Through Abandoned Boreholes*

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

The waste disposal panels provide the main source of colloids in the disposal system. Colloid transport within the Culebra as a result of long-term flow associated with future abandoned boreholes that intersect the waste disposal region are accounted for in PA calculations, as described in Sections 6.4.3.6 and 6.4.6.2.1. Consistent with the discussion in H24, colloid transport as a result of flow through future abandoned boreholes that do not intersect the waste disposal region has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The Culebra is the most transmissive unit in the disposal system and it is the most likely unit through which significant radionuclide transport could occur. Therefore, colloid transport in units other than the Culebra, as a result of flow through future abandoned boreholes, has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

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

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

SCR-5.2.2 Excavation-Induced Flow

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

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

Changes in groundwater flow due to HCN, and future potash mining are accounted for in PA calculations.

SCR-5.2.2.1.2 Summary of New Information

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

SCR-5.2.2.1.3 Screening Argument

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

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

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

SCR-5.2.2.1.3.2 *Hydrogeological Effects of Mining*

Potash mining in the Delaware Basin typically involves constructing vertical shafts to the elevation of the ore zone and then extracting the minerals in an excavation that follows the trend of the ore body. Potash has been extracted using conventional room and pillar mining, secondary mining where pillars are removed, and modified long-wall mining methods. Mining techniques used include drilling and blasting (used for mining langbeinite) and continuous mining (commonly used for mining sylvite). The DOE (Westinghouse 1994, pp. 2-17 to 2-19) reported investigations of subsidence associated with potash mining operations located near the WIPP. The reported maximum total subsidence at potash mines is about 1.5 m (5 ft), representing up to 66 percent of initial excavation height, with an observed angle of draw from the vertical at the edge of the excavation of 58 degrees. The DOE (Westinghouse 1994 pp. 2-22 to 2-23) found no evidence that subsidence over local potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the surface. However, subsidence and fracturing associated with mining in the McNutt in the vicinity of the WIPP may allow increased recharge to the Rustler units and affect the lateral hydraulic conductivity of overlying units, such as the Culebra, which could influence the direction and magnitude of fluid flow within the disposal system. Such ***Changes in Groundwater Flow Due to Mining*** are accounted for in calculations of undisturbed performance of the disposal system. The effects of any increased recharge that may be occurring are in effect included by using heads measured in 2000 (which should reflect that recharge) to calibrate Culebra transmissivity fields and calculate transport through those fields (Beauheim 2002). Changes (increases) in Culebra transmissivity are incorporated directly in the modeling of flow and transport in the Culebra (see Section 6.4.6.2.3).

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

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

SCR-5.2.2.1.4 Future Human EPs

Consistent with 40 CFR § 194.32(b), consideration of future mining may be limited to potash mining within the disposal system. Within the controlled area, the McNutt provides the only potash of appropriate quality. The extent of possible future potash mining within the controlled area is discussed in Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in 40 CFR § 194.32(b): the effects of future mining may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system. Thus, consistent with 40 CFR § 194.32(b), ***Changes in Groundwater Flow Due to Mining*** within the controlled area are accounted for in calculations of the disturbed performance of the disposal system (see Section 6.4.6.2.3).

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

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

Changes in geochemistry due to HCN potash mining have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Changes in geochemistry due to future mining have been eliminated from PA calculations on regulatory grounds.

SCR-5.2.2.2.2 Summary of New Information

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

SCR-5.2.2.2.3 Screening Argument

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

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

SCR-5.2.2.2.3.2 *Geochemical Effects of Mining*

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

SCR-5.2.2.2.3.3 *Future Human EPs*

Consistent with 40 CFR § 194.32(b), consideration of future mining may be limited to potash mining within the disposal system. Within the controlled area, the McNutt provides the only potash of appropriate quality. The extent of possible future potash mining within the controlled area is discussed in Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in 40 CFR § 194.32(b): the effects of future mining may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system. Thus, consistent with 40 CFR § 194.32(b), changes in groundwater flow due to mining within the controlled area are accounted for in calculations of the disturbed performance of the disposal system (see Section 6.4.6.2.3). Other potential effects, such as ***Changes in Groundwater Flow Due to Mining***, have been eliminated from PA calculations on regulatory grounds.

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

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

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

SCR-5.2.2.3.2 Summary of New Information

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

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

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

SCR-5.2.2.3.3 Screening Argument

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

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

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

Typically, solution mining is used for potash:

- when deposits are at depths in excess of 914 m (3000 ft) and rock temperatures are high or are geologically too complex to mine profitably using conventional underground mining techniques;
- to recover the potash pillars at the end of a mine's life; or

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

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

The impact on the WIPP of neighboring potash mines was examined in detail by D'Appolonia (1982) and evaluated the possible effects of ***Solution Mining for Potash*** or other evaporite minerals. According to D'Appolonia (1982), and in agreement with Heyn (1997) of IMC Global Inc, solution mining of langbeinite is not technically feasible because the ore is less soluble than the surrounding evaporite minerals. Solution mining of sylvite was unsuccessfully attempted in the past by the Potash Company of America and Continental Potash, both ore bodies currently owned by Mississippi Chemical. Failure of solution mining was attributed to low ore grade, thinness of the ore beds, and problems with heating and pumping injection water. Unavailability of water in the area would also impede implementation of this technique. For these reasons, solution mining is not currently used in the Carlsbad Potash District.

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

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

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

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

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

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

SCR-5.2.2.4.2 Summary of New Information

See summary for H58.

SCR-5.2.2.4.3 Screening Argument

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

SCR-5.2.2.4.4 Solution Mining for Brine

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

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

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

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

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

SCR-5.2.2.4.4.1 *Current Brine Wells within the Vicinity of WIPP*

Brine wells are classified as Class II injection wells. In the Delaware Basin, the process includes injecting fresh water into a salt formation to create a saturated brine solution which is then extracted and utilized as a drilling agent. These wells are tracked by the Delaware Basin Drilling Surveillance Program on a continuing basis. Supplemental information provided to the EPA in 1997 showed 11 brine wells in the Delaware Basin. Since that time, additional information has shown that there are 15 brine wells within the Delaware basin, of which four are plugged and abandoned. This results in 11 currently active brine wells. Table SCR-3 provides information on these wells.

Table SCR-3. Delaware Basin Brine Well Status

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

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

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

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

SCR-5.2.2.4.5 Solution Mining for Other Minerals

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

SCR-5.2.2.4.6 Solution Mining for Gas Storage

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

SCR-5.2.2.4.7 Solution Mining for Disposal

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

SCR-5.2.2.4.8 Effects of Solution Mining

SCR-5.2.2.4.8.1 *Subsidence*

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

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

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

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

SCR-5.2.2.4.8.2 *Hydrogeological Effects*

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

- Subsidence above a large dissolution cavity could change the vertical and lateral hydraulic conductivity of overlying units.
- Extraction of fresh water from aquifers for solution mining could cause local changes in pressure gradients.
- Loss of injected fresh water or extracted brine to overlying units could cause local changes in pressure gradients.

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

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

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

SCR-5.2.2.4.8.3 *Geochemical Effects*

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

SCR-5.2.2.4.9 Conclusion of Low Consequence

Brine production through solution mining takes place in the Delaware Basin, and the DOE assumes it will continue in the near future.

Despite oil and gas exploration and production taking place in the vicinity of the WIPP site, the nearest operating solution mine is more than 32 km (20 mi) from the WIPP site. These locations are too far from the WIPP site for any changes in hydrogeology or geochemistry, from subsidence or fresh water or brine leakage, to affect the performance of the disposal system. Thus, the effects of historical, current, near-future, and future ***Solution Mining for Other Resources*** in the Delaware Basin can be eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-5.2.3 Explosion-Induced Flow

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

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

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

SCR-5.2.3.1.2 Summary of New Information

No new information has been identified for this FEP.

SCR-5.2.3.1.3 Screening Argument

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

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

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

SCR-5.2.3.1.3.2 *Future Human EPs*

The criterion in 40 CFR § 194.32(a) relating to the scope of PAs limits the consideration of future human actions to mining and drilling. Also, consistent with 40 CFR § 194.33(d), PAs need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, ***Changes in Groundwater Flow Due to Explosions*** in the future have been eliminated from PA calculations on regulatory grounds.

SCR-5.3 Geomorphological Events and Processes

SCR-5.3.1 Land Use Changes

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

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

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

SCR-5.3.1.1.2 Summary of New Information

The Delaware Basin monitoring program monitors land use activities in the WIPP vicinity. This program has not identified new planned uses for land in the vicinity of the WIPP (DOE 2002). This FEP discussion has been updated with additional information about industrial land uses in the region.

SCR-5.3.1.1.3 Screening Argument

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

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

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

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

The Delaware Basin monitoring program monitors land use activities in the WIPP vicinity. This program has not identified new planned uses for land in the vicinity of the WIPP (DOE 2002). Therefore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), ***Land Use Changes*** in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.1.5 Future Human EPs

The criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." Therefore, no future ***Land Use Changes*** need be considered in the vicinity of the WIPP, and they have been eliminated from PA calculations on regulatory grounds.

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

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

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

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

SCR-5.3.1.2.2 Summary of New Information

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

SCR-5.3.1.2.3 Screening Argument

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

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

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

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

The Delaware Basin monitoring program monitors land use activities in the WIPP vicinity. This program has not identified new planned uses for land in the vicinity of the WIPP (DOE 2002). Therefore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), ***Land Use Changes*** in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.3.1.2.5 Future Human EPs

The criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." Therefore, no future ***Land Use Changes*** need be considered in the vicinity of the WIPP, and they have been eliminated from PA calculations on regulatory grounds.

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

SCR-5.4 Surface Hydrological Events and Processes

SCR-5.4.1 Water Control and Use

SCR-5.4.1.1 FEP Number(s): H42, H43, and H44
FEP Title(s): ***Damming of Streams and Rivers*** (H42)
Reservoirs (H43)
Irrigation (H44)

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

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

SCR-5.4.1.1.2 Summary of New Information

No new information has been identified related to these FEPs. Changes have been made for editorial purposes.

SCR-5.4.1.1.3 Screening Argument

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

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

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

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

SCR-5.4.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future ***Damming of Streams and Rivers, Reservoirs,*** *and* ***Irrigation*** have been eliminated from PA calculations on regulatory grounds.

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

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

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

SCR-5.4.1.2.2 Summary of New Information

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

SCR-5.4.1.2.3 Screening Argument

Irrigation and damming, as well as other forms of water control and use, could lead to localized changes in recharge, possibly leading to increased heads locally, thereby affecting flow directions and velocities in the Rustler and Dewey Lake. Surface activities, such as those associated with potash mining, could also affect soil and surface water chemistry. Note that the potential effects of geomorphological changes through land use are discussed in H40 and H41.

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

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

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

SCR-5.4.1.2.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future ***Lake Usage*** have been eliminated from PA calculations on regulatory grounds.

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

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

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

SCR-5.4.1.3.2 Summary of New Information

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

SCR-5.4.1.3.3 Screening Argument

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

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

Potash mining effluent and runoff from oil fields have altered soil and surface water chemistry in the vicinity of the WIPP. However, the performance of the disposal will not be sensitive to soil and surface water chemistry. Therefore, ***Altered Soil or Surface Water Chemistry by Human Activities*** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The effects of effluent from potash processing on groundwater flow are discussed in H37.

SCR-5.4.1.3.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future ***Altered Soil or Surface Water Chemistry by Human Activities*** have been eliminated from PA calculations on regulatory grounds.

SCR-5.5 Climatic Events and Processes

SCR-5.5.1 Anthropogenic Climate Change

SCR-5.5.1.1 FEP Number(s): H47, H48, and H49
FEP Title: ***Greenhouse Gas Effects*** (H47)
Acid Rain (H48)
Damage to the Ozone (N49)

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

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

SCR-5.5.1.1.2 Summary of New Information

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

SCR-5.5.1.1.3 Anthropogenic Climate Change

The effects of the current climate and natural climatic change are accounted for in PA calculations, as discussed in Section 6.4.9. However, human activities may also affect the future climate and thereby influence groundwater recharge in the WIPP region. The effects of anthropogenic climate change may be on a local to regional scale (***Acid Rain*** *(H48)*) or on a regional to global scale (***Greenhouse Gas Effects*** *(H47)* and ***Damage to the Ozone*** layer *(H49)*). Of these anthropogenic effects, only the ***Greenhouse Gas Effect*** could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in 40 CFR § 194.25, compliance assessments and PAs need not consider indirect anthropogenic effects on disposal system performance. Therefore, the effects of anthropogenic climate change have been eliminated from PA calculations on regulatory grounds.

SCR-5.6 Marine Events and Processes

SCR-5.6.1 Marine Activities

SCR-5.6.1.1.1 FEP Number(s): H50, H51 & H52
FEP Title(s): ***Costal Water Use*** (H50)
Seawater Use (H51)
Estuarine Water (H52)

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

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

SCR-5.6.1.1.2 Summary of New Information

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

SCR-5.6.1.1.3 Screening Argument

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

SCR-5.6.1.1.4 Historical, Current, and Near-Future Human EPs

The WIPP site is more than 800 km (480 mi) from the nearest seas, and hydrological conditions in the vicinity of the WIPP have not been affected by marine activities. Furthermore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), consideration of HCN human activities is limited to those activities that have occurred or are expected to occur in the vicinity of the disposal system. Therefore, Human EPs related to marine activities (such as ***Coastal Water Use, Seawater Use,*** *and* ***Estuarine Water*** use) have been eliminated from PA calculations on regulatory grounds.

SCR-5.6.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a) that limit the scope of consideration of future human actions in PAs to mining and drilling. Therefore, the effects of future marine activities (such as ***Coastal Water Use, Seawater Use,*** *and* ***Estuarine Water*** use) have been eliminated from PA calculations on regulatory grounds.

SCR-5.7 Ecological Events and Processes

SCR-5.7.1 Agricultural Activities

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

***Ranching* (H54)**
***Fish Farming* (H55)**

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

*The effects of HCN **Ranching** and **Arable Farming** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. The effects of changes in future **Ranching** and **Arable Farming** practices have been eliminated from PA calculations on regulatory grounds. **Fish Farming** has been eliminated from PA calculations on regulatory grounds.*

SCR-5.7.1.1.2 Summary of New Information

No new information has been identified related to these FEPs.

SCR-5.7.1.1.3 Screening Argument

Agricultural activities could affect infiltration and recharge conditions in the vicinity of the WIPP. Also, application of acids, oxidants, and nitrates during agricultural practice could alter groundwater geochemistry.

SCR-5.7.1.1.4 Historical, Current, and Near-Future Human EPs

Grazing leases exist for all land sections immediately surrounding the WIPP and grazing occurs within the controlled area (see Section 2.3.2.2). Although grazing and related crop production have had some control on the vegetation at the WIPP site, these activities are unlikely to have affected subsurface hydrological or geochemical conditions. The climate, soil quality, and lack of suitable water sources all mitigate against agricultural development of the region in the near future. Therefore, the effects of HCN ***Ranching** and **Arable Farming*** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), agricultural activities, such as ***Fish Farming***, that have not taken place and are not expected to take place in the near future in the vicinity of the WIPP have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.1.1.5 Future Human EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a) that limit the scope of consideration of future human activities in PAs to mining and drilling. Also, the criterion in 40 CFR § 194.25(a) concerned with predictions of the future states of society requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, the effects of changes in future agricultural practices (such as ***Ranching***, ***Arable Farming***, and ***Fish Farming***) have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.2 Social and Technological Development

SCR-5.7.2.1 FEP Number: H56
FEP Title: ***Demographic Change and Urban Development***

SCR-5.7.2.1.1 Screening Decision: SO-R (HCN)
SO-R (Future)

Demographic Change and Urban Development *in the near future and in the future have been eliminated from PA calculations on regulatory grounds.*

SCR-5.7.2.1.2 Summary of New Information

No new information has been identified for this FEP.

SCR-5.7.2.1.3 Screening Argument

Social and technological changes in the future could result in the development of new communities and new activities in the vicinity of the WIPP that could have an impact on the performance of the disposal system.

Demography in the WIPP vicinity is discussed in Section 2.3.2.1. The community nearest to the WIPP site is the town of Loving, 29 km (18 mi) west-southwest of the site center. There are no existing plans for urban developments in the vicinity of the WIPP in the near future. Furthermore, the criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and PAs "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, ***Demographic Change and Urban Development*** in the vicinity of the WIPP and technological developments have been eliminated from PA calculations on regulatory grounds.

SCR-5.7.2.2 FEP Number: H57
FEP Title: ***Loss of Records***

SCR-5.7.2.2.1 Screening Decision: NA (HCN)
DP (Future)

Loss of Records *in the future is accounted for in PA calculations.*

SCR-5.7.2.2.2 Summary of New Information

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

SCR-5.7.2.2.3 Screening Argument

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

SCR-6.0 WASTE AND REPOSITORY-INDUCED FEPS

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

SCR-6.1 Waste and Repository Characteristics

SCR-6.1.1 Repository Characteristics

SCR-6.1.1.1 FEP Number: W1
FEP Title: ***Disposal Geometry***

SCR-6.1.1.1.1 Screening Decision: UP

*The WIPP repository **Disposal Geometry** is accounted for in PA calculations.*

SCR-6.1.1.1.2 Summary of New Information

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

SCR-6.1.1.2 Screening Argument

Disposal *Geometry* is described in Chapter 3, Section 3.2 and is accounted for in the setup of PA calculations (Section 6.4.2).

SCR-6.1.2 Waste Characteristics

SCR-6.1.2.1 FEP Number: W2 and W3
FEP Title: ***Waste Inventory***
Heterogeneity of Waste Forms

SCR-6.1.2.1.1 Screening Decision: UP

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

SCR-6.1.2.1.2 Summary of New Information

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

SCR-6.1.2.1.3 Screening Argument

Waste characteristics, comprising the ***Waste Inventory*** and the ***Heterogeneity of Waste Forms***, are described in Chapter 4.0. The waste inventory is accounted for in PA calculations in deriving the dissolved actinide source term and gas generation rates (Sections 6.4.3.5 and 6.4.3.3). The distribution of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste within the repository leads to room scale heterogeneity of the waste forms, which is accounted for in PA calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion (Section 6.4.7).

SCR-6.1.3 Container Characteristics

SCR-6.1.3.1 FEP Number: W4
FEP Title: ***Container Form***

SCR-6.1.3.1.1 Screening Decision: SO-C - Beneficial

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

SCR-6.1.3.1.2 Summary of New Information

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

SCR-6.1.3.1.3 Screening Argument

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

SCR-6.1.3.2 FEP Number: W5
FEP Title: ***Container Material Inventory***

SCR-6.1.3.2.1 Screening Decision: UP

*The **Container Material Inventory** is accounted for in PA calculations.*

SCR-6.1.3.2.2 Summary of New Information

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

SCR-6.1.3.2.3 Screening Argument

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

SCR-6.1.4 Seal Characteristics

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

SCR-6.1.4.1.1 Screening Decision: UP

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

SCR-6.1.4.1.2 Summary of New Information

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

SCR-6.1.4.1.3 Screening Argument

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

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

SCR-6.1.4.2.1 Screening Decision: SO-C Beneficial

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

SCR-6.1.4.2.2 Summary of New Information

In the CCA, ***Seal Chemical Composition*** was screened out on the basis of predicted beneficial consequences, which are not credited in PA calculations. Recent publications provide support for the screening argument that chemical interactions between the cement seals and the brine will be of beneficial consequence to the performance of the disposal system, through sorption and sequestration of radionuclides. Ignoring adsorption simplifies the PA calculations, and is expected to produce somewhat more conservative results. However, because little or no upward flow is predicted to occur through the seals, the overall effect on PA results may not be significant.

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

SCR-6.1.4.2.3 Screening Argument

Seal (shaft seals, panel closures, and drift closures) characteristics, including ***Seal Geometry*** and ***Seal Physical Properties***, are described in CCA Chapter 3.0 and are accounted for in PA calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials. The effect of shaft ***Seal Chemical Composition*** on actinide speciation and mobility has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.4.2.4 Repository Seals

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

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

The effects of cementitious seals on groundwater chemistry have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.1.5 Backfill Characteristics

SCR-6.1.5.1 FEP Number: W9
FEP Title: ***Backfill Physical Properties***

SCR-6.1.5.1.1 Screening Decision: SO-C

Backfill Physical Properties *have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

SCR-6.1.5.1.2 Summary of New Information

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

SCR-6.1.5.1.3 Screening Argument

A chemical backfill is being added to the disposal room to buffer the chemical environment. The backfill characteristics were previously described in CCA Appendix BACK with additional information contained in Appendix BARRIERS. The mechanical and thermal effects of backfill are discussed in W35 and W72 respectively, where they have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. Backfill will result in an initial permeability for the disposal room lower than that of an empty cavity, so neglecting the hydrological effects of backfill is a conservative assumption with regard to brine inflow and radionuclide migration. Thus, ***Backfill Physical Properties*** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.1.5.2 FEP Number: W10
FEP Title: ***Backfill Chemical Composition***

SCR-6.1.5.2.1 Screening Decision: UP

*The **Backfill Chemical Composition** is accounted for in PA calculations.*

SCR-6.1.5.2.2 Summary of New Information

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

SCR-6.1.5.2.3 Screening Argument

A chemical backfill is added to the disposal room to buffer the chemical environment. The backfill characteristics are described in Section 6.4.3.4. The mechanical and thermal effects of backfill are discussed in FEP W35 and FEP W72, respectively, where they have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. ***Backfill Chemical Composition*** is accounted for in PA calculations in deriving the dissolved and colloidal actinide source terms (Section 6.4.3).

SCR-6.1.6 Post-Closure Monitoring Characteristics

SCR-6.1.6.1 FEPs Number: W11
FEP Title: ***Post-Closure Monitoring***

SCR-6.1.6.1.1 Screening Decision: SO-C

*The potential effects of **Post-Closure Monitoring** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

SCR-6.1.6.1.2 Summary of New Information

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

SCR-6.1.6.1.3 Screening Argument

Post-Closure Monitoring is required by 40 CFR § 191.14(b) as an assurance requirement to "detect substantial and detrimental deviations from expected performance." The DOE has designed the monitoring program (see CCA Appendix MON) so that the monitoring methods employed are not detrimental to the performance of the disposal system (40 CFR 194.42(d)). Non-intrusive monitoring techniques are used so that ***Post-Closure Monitoring*** would not impact containment or require remedial activities. In summary, the effects of monitoring have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.2 Radiological Features, Events, and Processes

SCR-6.2.1 Radioactive Decay and Heat

SCR-6.2.1.1 FEP Number: W12
FEP Title: ***Radionuclide Decay and Ingrowth***

SCR-6.2.1.1.1 Screening Decision: UP

Radionuclide Decay and Ingrowth *are accounted for in PA calculations.*

SCR-6.2.1.1.2 Summary of New Information

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

SCR-6.2.1.1.3 Screening Argument

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

SCR-6.2.1.2 FEP Number: W13
FEP Title: ***Heat From Radioactive Decay***

SCR-6.2.1.2.1 Screening Decision: SO-C

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

SCR-6.2.1.2.2 Summary of New Information

WIPP transportation restrictions do not allow the thermal load of the WIPP to exceed 10 kW/acre (NRC 2002). Transportation requirements restrict the thermal load from RH-TRU waste containers to no more than 300 watts per container (NRC 2002). However, the limit on the surface dose equivalent rate of the RH-TRU containers (1,000 rem/hr) is more restrictive and equates to a thermal load of only about 60 watts per container. Based on the thermal loads permitted, the maximum temperature rise in the repository from radioactive decay heat should be less than 2°C (3.6°F). The 2003 update to the TWBIR Revision 3 (Appendix DATA, Attachment F) indicates that the radionuclide inventory is lower than previously estimated for the CCA.

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

SCR-6.2.1.3 Screening Argument

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

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

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

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

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

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

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

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

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

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

- Calculate the absorbed dose rate for gamma radiation corresponding to the maximum surface dose equivalent rate of 1000 rem per hour. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because the maximum dose rate from neutrons is 270 millirem per hour, and the corresponding neutron heating rate will be insignificant.

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

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

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

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

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

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

Temperature increases will be greater at locations where the thermal power of an RH-TRU container is 60 W, if any such containers are emplaced. Sanchez and Trellue (1996) estimated the temperature increase at the surface of a 60 W RH-TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 W/m^3 (2 W/ft^3). These conditions represent conservative assumptions because the thermal load will decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3°C (5.4°F).

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

The previous FEPs screening arguments for the CCA used a bounding radioactivity heat load of 0.5 watts/drum for the CH-TRU waste containers. With a total CH-TRU volume of 168,500 m^3 (~5,950,000 ft^3) this corresponds to approximately 810,000 55-gallon drum equivalents with a corresponding heat load of > 400 kW used for the CCA FEPs screening arguments. From Sanchez and Trellue (1996), it can be seen that a realistic assessment of the heat load, based on radionuclide inventory data in the Transuranic Waste Baseline Inventory Report (TWBIR) is less than 100 kW. Thus, the CCA FEPs incorporate a factor of safety of at least four.

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

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

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

SCR-6.2.1.4.1 Screening Decision: SO-P

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

SCR-6.2.1.4.2 Summary of New Information

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

SCR-6.2.1.4.3 Screening Argument

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

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

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

Screening arguments made in Rechard et al. (1996) are represented in greater detail in Rechard et al. (2000, 2001). A major finding among the analysis results in the screening arguments is the determination that fissile material would need to be reconcentrated by three orders of magnitude in order to be considered in a criticality scenario. These previous arguments were based on radionuclide information from Revision 3 of the TWBIR (DOE 1996b). Of the 135 radionuclides presented in that TWBIR database, only 17 are possible contributors to fissile material. Table SCR-4 identifies these nuclides along with their conversion factors for specific activity and ^{239}Pu fissile gram equivalents (^{239}Pu fissile gram equivalent (FGE) per ANSI/ANS-18.5).

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

SCR-6.2.2 Radiological Effects on Material Properties

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

SCR-6.2.2.1.1 Screening Decision: SO-C

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

SCR-6.2.2.1.2 Summary of New Information

The FEPs screening argument has been updated by referencing new radiological waste data. The screening decision for these FEPs has not been affected or changed by these new data.

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

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

1 Half-life data originally taken from ORIGEN2 decay library (Croff 1980). Data values presented in Ref. Sanchez 1996 (WIPP WPO# 037404).

2 Mass excess values originally taken from Nuclear Wallet Cards (Tuli 1985). Data values presented in Ref. Sanchez 1996 (WIPP WPO# 037404).

3 Atomic weight calculated from: ATWT (AMU) = AN (atomic mass number) – ME (mass difference in MeV, ME of C^{12} = 0) / 931.4943 (MeV per AMU, Parrington et al. 1996, pg. 58).

4 Specific Activity calculated from: A'= (Na ln(2))/(ATWT half-life), Ref. Turner 1992, pg. 64 and A (Ci/gm) = A'(Bq/gm) / 3.7E+10 (Bq/Ci), Turner 1992, pg. 43, where Na = Avogadro's number = 6.02213676E+23 (atom/mole, Parrington, pg.59).

5 FGE (^{239}Pu based) data values from NuPac 1989 (TRUPACT-II SAR/Table 10.1/pg. 1.3.7-51 (data originally from Ref. ANSI/ANS-8.15 1981).

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

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

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

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

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

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

SCR-6.2.2.1.3 Screening Argument

Ionizing radiation can change the physical properties of many materials. Strong radiation fields could lead to damage of waste matrices, brittleness of the metal containers, and disruption of any crystalline structure in the seals. The low level of activity of the waste in the WIPP is unlikely to generate a strong radiation field. According to the new *inventory* data, the total radionuclide inventory decreased from 7.44×10^6 (DOE 1996b) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Such a small decrease will not change the original screening argument. In addition, PA calculations assume instantaneous container failure and waste dissolution according to the source-term model (see Sections 6.4.3.4, 6.4.3.5, and 6.4.3.6. Therefore, ***Radiological Effects on the Properties of the Waste, Container, and Seals*** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3 Geological and Mechanical Features, Events, and Processes

SCR-6.3.1 Excavation-Induced Changes

SCR-6.3.1.1 FEP Number: W18 and W19
FEP Title: ***Disturbed Rock Zone*** (W18)
Excavation-Induced Change in Stress (W19)

SCR-6.3.1.1.1 Screening Decision: UP

Excavation-induced host rock fracturing through formation of a disturbed rock zone (*DRZ*) *and changes in stress are accounted for in PA calculations.*

SCR-6.3.1.1.2 Summary of New Information

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

SCR-6.3.1.1.3 Screening Argument

Construction of the repository has caused local ***excavation-induced changes in stress*** in the surrounding rock as discussed in Section 3.3.1.5. This has led to failure of intact rock around the opening, creating a DRZ of fractures. On completion of the WIPP excavation, the extent of the induced stress field perturbation will be sufficient to have caused dilation and fracturing in the anhydrite layers a and b, MB139, and, possibly, MB138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and marker beds will alter the permeability and effective porosity of the rock around the repository, providing enhanced pathways for flow of gas and brine between the waste-filled rooms and the nearby interbeds. This excavation-induced, host-rock fracturing is accounted for in PA calculations (Section 6.4.5.3).

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

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

SCR-6.3.1.2.1 Screening Decision: UP

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

SCR-6.3.1.2.2 Summary of New Information

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

SCR-6.3.1.2.3 Screening Argument

Salt Creep will lead to ***Changes in the Stress Field***, compaction of the waste and containers, and consolidation of the long-term components of the sealing system. It will also tend to close fractures in the DRZ, leading to reductions in porosity and permeability, increases in pore fluid pressure, and reductions in fluid flow rates in the repository. ***Salt Creep*** in the Salado is accounted for in PA calculations (Section 6.4.3.1). The long-term repository seal system relies on the consolidation of the crushed-salt seal material and healing of the DRZ around the seals to achieve a low permeability under stresses induced by salt creep. Seal performance is discussed further in FEPs W36 and W37.

SCR-6.3.1.3 FEP Number: W22
FEP Title: ***Roof Falls***

SCR-6.3.1.3.1 Screening Decision: UP

The potential effects of roof falls on flow paths are accounted for in PA calculations.

SCR-6.3.1.3.2 Summary of New Information

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

SCR-6.3.1.3.3 Screening Argument

Instability of the DRZ could to lead to localized ***Roof Falls*** in the first few hundred years. If instability of the DRZ causes roof falls, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep. In the long term, the effects of roof falls in the repository are likely to be minor because **Salt *Creep*** will reduce the void space and the potential for ***Roof Falls*** as well as leading to healing of any roof material that has fallen into the rooms. However, because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the PA assumes that a higher permeability zone remains for the long term. Thus, the potential effects of ***Roof Falls*** on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ.

SCR-6.3.1.4 FEP Number(s): W23 and W24
FEP Title(s): ***Subsidence*** (W23)
Large Scale Rock Fracturing (W24)

SCR-6.3.1.4.1 Screening Decision(s): SO-C (W23)
SO-P (W24)

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

SCR-6.3.1.4.2 Summary of New Information

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

SCR-6.3.1.4.3 Screening Argument

Instability of the DRZ could to lead to localized ***Roof Falls*** in the first few hundred years. If instability of the DRZ causes ***Roof Falls***, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep and the local lithologies. In the long term, the effects of ***Roof Falls*** in the repository are likely to be minor because ***Salt Creep*** will reduce the void space and the potential for roof falls as well as leading to healing of any roof material that has fallen into the rooms. Because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the PA assumed that a higher permeability zone remained for the long term. The PAVT modified the DRZ permeability to a sampled range. Thus, the potential effects of ***Roof Falls*** on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ.

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

Subsidence over potash mines will be much greater than subsidence over the WIPP because of the significant differences in stratigraphic position, depth, extraction ratio, and layout. The WIPP site is located stratigraphically lower than the lowest potash mine, which is near the base of the McNutt Potash Member (hereafter called the McNutt). At the WIPP site, the base of the

McNutt is about 150 m (490 ft) above the repository horizon. Also, the WIPP rock extraction ratio in the waste disposal region will be about 22 percent, as compared to 65 percent for the lowest extraction ratios within potash mines investigated by the DOE (Westinghouse 1994, p. 2-17).

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

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

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

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

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

$$K = \frac{w^3 \rho g N}{12 \mu D}, \qquad (10)$$

where w is the fracture aperture, ρ is the fluid density (taken to be 1,000 kg/m^3), g is the acceleration due to gravity (9.79 m (32 ft) per second squared), μ is the fluid viscosity (taken as 0.001 pascal seconds), D is the effective Culebra thickness (7.7 m (26.3 ft)), and N is the number of fractures. For 10 fractures with a fracture aperture, w, of 6×10^{-5} m (2×10^{-4} ft), the Culebra hydraulic conductivity, K, is approximately 7 m per year (2×10^{-7} m (6.5×10^{-7} ft) per second). The values of the parameters used in this calculation are within the range of those expected for the Culebra at the WIPP site (Appendix PA, Attachment TFIELD).

The amount of opening of each fracture as a result of subsidence-induced tensile vertical strain, ε, (assuming rigid rock) is $D\varepsilon/N$ 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 (1.9×10^{-4} ft). Using the values for ρ, g, and μ, above, the vertical hydraulic conductivity of the Culebra can then be calculated, through an equation similar to above, to be 7 m (23 ft) per year (2×10^{-7} m (6.5×10^{-7} ft) per second). Thus, vertical hydraulic conductivity in the Culebra may be created as a result of repository-induced ***Subsidence***, although this is expected to be insignificant.

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

SCR-6.3.2 Effects of Fluid Pressure Changes

SCR-6.3.2.1 FEP Number: W25 and W26
FEP Title: ***Disruption Due to Gas Effects*** (W25)
Pressurization (W26)

SCR-6.3.2.1.1 Screening Decision: UP

*The mechanical effects of gas generation through **Pressurization** and **Disruption Due to Gas** flow are accounted for in PA calculations.*

SCR-6.3.2.1.2 Summary of New Information

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

SCR-6.3.2.1.3 Screening Argument

The mechanical effects of gas generation, including the slowing of creep closure of the repository due to gas ***Pressurization***, and the fracturing of interbeds in the Salado through ***Disruption Due to Gas Effects*** are accounted for in PA calculations (Sections 6.4.5.2 and 6.4.3.1).

SCR-6.3.3 Effects of Explosions

SCR-6.3.3.1 FEP Number: W27
FEP Title: ***Gas Explosions***

SCR-6.3.3.1.1 Screening Decision: UP

*The potential effects of **Gas Explosions** are accounted for in PA calculations.*

SCR-6.3.3.1.2 Summary of New Information

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

Explosive gas mixtures could collect in the head space above the waste in a closed panel. The most explosive gas mixture potentially generated will be a mixture of hydrogen, methane, and oxygen which will convert to CO_2 and water on ignition. This means that there is little likelihood of a ***Gas Explosion***in the long term, because the rooms and panels are expected to become anoxic and oxygen depleted. Compaction through salt creep will also greatly reduce any void space in which the gas can accumulate. Analysis (see Appendix BARRIERS**,** Attachment PCS) indicates that the most explosive mixture of hydrogen, methane, and oxygen will be present in the void space approximately 20 years after panel-closure emplacement. This possibility of an explosion prior to the occurrence of anoxic conditions is considered in the design of the operational panel closure. The effect of such an explosion on the DRZ is expected to be no more severe than a ***Roof Fall*** which is accounted for in the PA calculations (FEP W22).

SCR-6.3.3.2 FEP Number: W28
FEP Title: ***Nuclear Explosions***

SCR-6.3.3.2.1 Screening Decision: SO-P

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

SCR-6.3.3.2.2 Summary of New Information

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

SCR-6.3.3.2.3 Screening Argument

Nuclear explosions have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years. For a ***Nuclear Explosions*** to occur, a critical mass of Pu would have to undergo rapid compression to a high density. Even if a critical mass of Pu could form in the system, there is no mechanism for rapid compression. Radioactivity inventories for the fissile radionuclides used in DOE (1996a) and CRA-2004 are presented in Table SCR-6. The updated information for the WIPP disposal inventory of fissile material (Appendix DATA, Attachment F; Leigh 2003a) indicates that the expected WIPP-scale quantity is 43 percent lower than previously estimated in TWBIR Rev. 3 (DOE 1996b). Thus, all CRA-2004 criticality screening arguments are conservatively bounded by the previous CCA screening arguments (Rechard et al. 1996, 2000, and 2001).

SCR-6.3.4 Thermal Effects

SCR-6.3.4.1 FEP Number: W29, W30, W31, W72, and W73
FEP Title: ***Thermal Effects on Material Properties*** (W29)
Thermally-Induced Stress Changes (W30)
Differing Thermal Expansion of Repository Components (W31)
Exothermic Reactions (W72)
Concrete Hydration (W73)

SCR-6.3.4.1.1 Screening Decision: SO-C

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

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

SCR-6.3.4.1.2 Summary of New Information

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

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

SCR-6.3.4.1.3 Screening Argument

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

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

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

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

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

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

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

Temperature rises (^oC) by exothermic reactions are revised as follows:

Table SCR-7. CCA and CRA Exothermic Temperature Rises

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

[1] All values are shown in degrees Celsius

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

For the CCA conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (10.8°F) above ambient room temperature (about 27°C (80°F)) (Bennett et al. 1996). A temperature rise of 6°C (10.8°F) represented the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Revised maximum temperature rises by exothermic reactions for CRA-2004 are still less than 10°C (18°F) (as shown in Table SCR-7). Such small temperature changes cannot affect material properties. Thus, ***Thermal Effects on Material Properties*** in the repository have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.3.5 Mechanical Effects on Material Properties

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

SCR-6.3.5.1.1 Screening Decision: UP

Consolidation of Waste *is accounted for in PA calculations.* ***Consolidation of Seals*** *and* ***Mechanical Degradation of Seals*** *are accounted for in PA calculations. Flow through isolated, unsealed* ***Underground Boreholes*** *is accounted for in PA calculations.*

SCR-6.3.5.1.2 Summary of New Information

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

SCR-6.3.6.1.3 Screening Argument

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

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

The site investigation program has also involved the drilling of boreholes from within the excavated part of the repository. Following their use for monitoring or other purposes, these ***Underground Boreholes*** will be sealed where practical, and ***Salt Creep*** will also serve to consolidate the seals and to close the boreholes. Any boreholes that remain unsealed will connect the repository to anhydrite interbeds within the Salado, and thus provide potential pathways for radionuclide transport. PA calculations account for fluid flow to and from the interbeds by assuming that the DRZ has a permanently enhanced permeability that allows flow of repository brines into specific anhydrite layers and interbeds. This treatment is also considered to account for the effects of any unsealed boreholes.

SCR-6.3.5.2 FEP Number: W33
FEP Title: ***Movement of Containers***

SCR-6.3.5.2.1 Screening Decision: SO-C

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

SCR-6.3.5.2.2 Summary of New Information

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

SCR-6.3.5.2.3 Screening Argument

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

For the CCA, the density of the compacted waste and the grain density of the halite in the Salado were assumed to be 2,000 kg/m^3 and 2,163 kg/m^3, respectively. Because this density contrast is small, the movement of containers relative to the salt was considered minimal, particularly when drag forces on the waste containers were also considered. In addition, vertical movement initiated in response to thermally-induced density changes for high-level waste containers of a similar density to those at the WIPP were calculated to be approximately 0.35 m (1 ft) (Dawson and Tillerson 1978, p. 22). This calculated movement was considered conservative given that containers at the WIPP will generate much less heat and will, therefore, move less. As a result, container movement was eliminated from PA calculations on the basis of low consequences to the performance of the disposal system.

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

The first factor is changes in density of the waste form. For the most part, waste density will remain as assumed in the CCA. According to new *inventory* data (Appendix DATA, Attachment F), the revised waste density has changed by at most 10 percent (lower). Some future waste streams may however be more highly compacted, perhaps having a density roughly three times greater than that assumed in the CCA. In calculations of container movement, Dawson and Tillerson (1978, p. 22) varied container density by nearly a factor of three (from 2,000 kg/m^3 (125 lb/ft^3) to 5,800 kg/m^3 (362 lb/ft^3)) and found that an individual dense container could move vertically as much as about 28 m (92 ft). Given the geologic environment of the WIPP, a container would likely encounter a dense stiff unit (such as an anhydrite stringer) that would arrest further movement far short of this upper bound; however, because of the massive thickness of the Salado salt, even a movement of 28 m (92 ft) would have little impact on performance.

The second inventory factor that could affect container movement is the composition of the waste (and backfills) relative to its heat production. Radioactive decay, ***Nuclear Criticality***, and exothermic reactions are three possible sources of heat in the WIPP repository. According to the new inventory data, the total radionuclide inventory decreases from 7.44×10^6 (CCA) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease. Such a small change will not result in a significant deviation from the possible temperature rise predicted in the CCA. As shown in Section SCR.6.3.4 (FEPs W72 and W73), temperature rises from exothermic reactions are quite small (see Table SCR-7). Note that the revised maximum temperature rises by exothermic reactions are still less than 10^{o}C (18°F).

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

SCR-6.3.5.3 FEP Number: W34
FEP Title: ***Container Integrity***

SCR-6.3.6.3.1 Screening Decision: SO-C Beneficial

Container Integrity *has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.*

SCR-6.3.5.3.2 Summary of New Information

No new information has been identified relating to this FEP. Editorial changes have been made to the FEP screening argument.

SCR-6.3.5.3.3 Screening Argument

Container Integrity is required only for waste transportation. As in the CCA, the CRA-2004 calculations show that a significant fraction of steel and other Fe-base materials will remain undegraded over 10,000 years (see Helton et al. 1998). For all undisturbed cases, at least 30 percent of the steels will remain uncorroded at the end of 10,000 years. In addition, it is assumed in both CCA and CRA-2004 calculations that there is no microbial degradation of plastic container materials in 75 percent of PA realizations (Wang and Brush 1996). All these undegraded container materials will (1) prevent the contact between brine and radionuclides; and (2) decrease the rate and extent of radionuclide transport due to high tortuosity along the flow pathways and, as a result, increase opportunities for metallic iron and corrosion products to beneficially reduce radionuclides to lower oxidation states. Therefore, the ***Container Integrity*** can be eliminated on the basis of its beneficial effect on retarding radionuclide transport. Both ***CCA*** and CRA-2004 assume instantaneous container failure and waste dissolution according to the source-term model.

SCR-6.3.5.4 FEP Number: W35
FEP Title: ***Mechanical Effects of Backfill***

SCR-6.3.5.4.1 Screening Decision: SO-C

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

SCR-6.3.5.4.2 Summary of New Information

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

SCR-6.3.5.4.3 Screening Argument

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

SCR-6.3.5.5 FEP Number: W38
FEP Title: ***Investigation Boreholes***

SCR-6.3.5.5.1 Screening Decision: NA

SCR-6.3.5.5.2 Summary of New Information

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

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

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

SCR-6.4.1 Repository-Induced Flow

SCR-6.4.1.1 FEP Number: W40 and W41
FEP Title: ***Brine Inflow*** (W40)
Wicking (W41)

SCR-6.4.1.1.1 Screening Decision: UP

Two-phase brine and gas flow and capillary rise (wicking) in the repository and the Salado are accounted for in PA calculations.

SCR-6.4.1.1.2 Summary of New Information

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

SCR-6.4.1.1.3 Screening Argument

Brine Inflow to the repository may occur through the DRZ, impure halite, anhydrite layers, or clay layers. Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Two-phase flow of brine and gas in the repository and the Salado is accounted for in PA calculations (Section 6.4.3.2).

Capillary rise (or ***Wicking***) is a potential mechanism for liquid migration through unsaturated zones in the repository. Capillary rise in the waste material could affect gas generation rates, which are dependent on water availability. Potential releases due to drilling intrusion are also influenced by brine saturations and therefore by ***Wicking***. Capillary rise is therefore accounted for in PA calculations (Section 6.4.3.2).

SCR-6.4.2 Effects of Gas Generation

SCR-6.4.2.1 FEP Number: W42
FEP Title: ***Fluid Flow Due to Gas Production***

SCR-6.4.2.1.1 Screening Decision: UP

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

SCR-6.4.2.1.2 Summary of New Information

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

SCR-6.4.2.1.3 Screening Argument

Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Gas may flow from the repository through the DRZ, impure halite, anhydrite layers, or clay layers. The amount of water available for reactions and microbial activity will impact the amounts and types of gases produced (W44 through W55). Gas generation rates, and therefore repository pressure, may change as the water content of the repository changes. Pressure changes and ***Fluid Flow Due to Gas Production*** in the repository and the Salado are accounted for in PA calculations through modeling the two-phase flow (Section 6.4.3.2).

SCR-6.4.3 Thermal Effects

SCR-6.4.3.1 FEP Number: W43
FEP Title: ***Convection***

SCR-6.4.3.1.1 Screening Decision: SO-C

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

SCR-6.4.3.1.2 Summary of New Information

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

SCR-6.4.3.1.3 Screening Argument

Temperature differentials in the repository could initiate ***Convection.*** The resulting thermally-induced brine flow or thermally-induced two-phase flow could influence contaminant transport. Potentially, thermal gradients in the disposal rooms could drive the movement of water vapor. For example, temperature increases around waste located at the edges of the rooms could cause evaporation of water entering from the DRZ. This water vapor could condense on cooler waste containers in the rooms and could contribute to brine formation, corrosion, and gas generation.

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

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

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

where α_i (per degree) is the coefficient of expansion of the i^{th} component, k_i is the intrinsic permeability (square meters), μ_i is the fluid viscosity (pascal second), ρ_{i0} (kilograms per cubic meter) is the fluid density at a reference point, g is the acceleration of gravity, and ΔT is the change in temperature. This velocity may be evaluated for the brine and gas phases expected in the waste disposal region.

For a temperature increase of 10°C (18°F), the characteristic velocity for convective flow of brine in the DRZ around the concrete shaft seals is approximately 7×10^{-4} m (2.3×10^{-3} ft) per year (2×10^{-11} m (6.6×10^{-11} ft) per second), and the characteristic velocity for convective flow of gas in the DRZ is approximately 1×10^{-3} m (3.2×10^{-3} ft) per year (3×10^{-11} m (9.8×10^{-11} ft) per second) (Hicks 1996). For a temperature increase of 25°C (45°F), the characteristic velocity for convective flow of brine in the concrete seals is approximately 2×10^{-7} m (6.5×10^{-7} ft) per year (6×10^{-15} m (1.9×10^{-14} ft) per second), and the characteristic velocity for convective flow of gas in the concrete seals is approximately 3×10^{-7} m (9.8×10^{-7} ft) per year (8×10^{-15} m (2.6×10^{-4} ft) per second) (Hicks 1996). These values of Darcy velocity are much smaller than the expected values associated with ***Brine Inflow*** to the disposal rooms of fluid flow resulting from gas generation. In addition, the buoyancy forces generated by smaller temperature contrasts in the DRZ, resulting from backfill and ***Concrete Hydration*** and ***Radioactive Decay***, will be short-lived and insignificant compared to the other driving forces for fluid flow. The short-term concrete seals will be designed to function as barriers to fluid flow for at least 100 years after emplacement, and seal permeability will be minimized (Wakeley et al. 1995). Thus, temperature increases associated with ***Concrete Hydration*** will not result in significant buoyancy driven fluid flow through the concrete seal system. In summary, temperature changes in the disposal system will not cause significant thermal ***cConvection***. Furthermore, the induced temperature gradients will be insufficient to generate water vapor and drive significant moisture migration.

Temperature effects on fluid viscosity would be most significant in the DRZ surrounding the hydrating concrete seals (where temperatures of approximately 38°C (100°F) are expected). The viscosity of pure water decreases by about 19 percent over a temperature range of between 27°C (80°F) and 38°C (100°F) (Batchelor 1973, p. 596). Although at a temperature of 27°C (80°F), the viscosity of Salado brine is about twice that of pure water (Rechard et al. 1990, a-19), the magnitude of the variation in brine viscosity between 27°C (80°F) and 38°C (100°F) will be similar to the magnitude of the variation in viscosity of pure water. The viscosity of air over this temperature range varies by less than seven percent (Batchelor 1973, p. 594) and the viscosity of gas in the waste disposal region over this temperature range is also likely to vary by less than seven percent. The Darcy fluid flow velocity for a porous medium is inversely proportional to the fluid viscosity. Thus, increases in brine and gas flow rates may occur as a result of viscosity variations in the vicinity of the concrete seals. However, these viscosity variations will persist only for a short period in which temperatures are elevated, and, thus, the expected variations in brine and gas viscosity in the waste disposal region will not affect the long-term performance of the disposal system significantly.

For the CCA conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (10.8°F). A temperature rise of 6°C (10.8°F) represented the maximum that could occur as a result of any combination of

Exothermic Reactions occurring simultaneously. Revised maximum temperature rises by ***Exothermic Reactions*** for CRA-2004 are still less than 10 °C (18°F) (as shown in Table SCR-7). Such small temperature changes cannot affect material properties.

In summary, temperature changes in the disposal system will not cause significant thermally-induced two-phase flow. Thermal ***cConvection*** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5 Geochemical and Chemical Features, Events, and Processes

SCR-6.5.1 Gas Generation

SCR-6.5.1.1 FEP Number: W44, W45, and W48
FEP Titles: ***Degradation of Organic Material*** (W44)
Effects of Temperature on Microbial Gas Generation (W45)
Effects of Biofilms on Microbial Gas Generation (W48)

SCR-6.5.1.1.1 Screening Decision: UP

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

SCR-6.5.1.1.2 Summary of New Information

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

SCR-6.5.1.1.3 Screening Argument

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

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

SCR-6.5.1.1.3.1 *Effects of Temperature on Microbial Gas Generation*

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

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

As discussed in FEPs W72 and W73, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5.3°C (9.5°F), resulting from ***Brine Inflow*** following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature rise of about 7.9°C (14.2°F) (see W72). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 10°C (18°F) represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

Relatively few data exist on the ***Effects of Temperature on Microbial Gas Generation*** under expected WIPP conditions. Molecke (1979, p. 4) summarized microbial gas generation rates observed during a range of experiments. Increases in temperature from ambient up to 40°C (104°F) or 50°C (122°F) were reported to increase gas production, mainly via the degradation of cellulosic waste under either aerobic or anaerobic conditions (Molecke 1979, p. 7). Above 70°C (158°F), however, gas generation rates were generally observed to decrease. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates, representing likely states within the repository. Gas generation rates were presented as ranges with upper and lower bounds as estimates of uncertainty (Molecke 1979, p. 7). Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). These experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. These experiments were carried out at a reference temperature of 30°C (86°F), based on the average temperature expected in the repository. Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Section 6.4.3.3. The effects of temperature on microbial gas generation are implicitly incorporated in the gas generation rates used.

SCR-6.5.1.1.3.2 *Effects of Biofilms on Microbial Gas Generation*

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

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

Molecke (1979, p. 4) summarized microbial gas generation rates observed during a range of experimental studies. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates representing likely states within the repository. However, the effect of biofilm formation in these experiments was uncertain. Molecke (1979, p. 7), presented gas generation rates as ranges, with upper and lower bounds as estimates of uncertainty. Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). Their experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. Under the more favorable conditions for microbial growth established during the experiments, the development of populations of halophilic microbes and associated biofilms was evidenced by observation of an extracellular, carotenoid pigment, bacterioruberin, in the culture bottles (Francis and Gillow 1994, p. 59). Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Section 6.4.3.3. The ***Effects of Biofilms on Microbial Gas Generation*** rates are implicitly incorporated in the gas generation rates.

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

SCR-6.5.1.2 FEP Number: W46
FEP Title: ***Effects of Pressure on Microbial Gas Generation***

SCR-6.5.1.2.1 Screening Decision: SO-C

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

SCR-6.5.1.2.2 Summary of New Information

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

SCR-6.5.1.2.3 Screening Argument

Directly relevant to WIPP conditions, the gas generation experiments with actual waste components at Argonne National Laboratory provide no indication of any enhancement of pressured nitrogen atmosphere (2150 psia) on microbial gas generation (Felicione et al. 2001). In addition, microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials in the repository, will produce mainly CO_2 and methane with minor amounts of nitrogen oxide, nitrogen, and hydrogen sulfide. The accumulation of these gaseous species will contribute the total pressure in the repository. Increases in the partial pressures of these reaction products could potentially limit gas generation reactions. However, such an effect is not taken into account in WIPP PA calculations. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. Microbial gas generation from ***Degradation of Organic Material*** (W44) is accounted for in PA calculations.

Chemical reactions may occur depending on, among other things, the concentrations of available reactants, the presence of catalysts and the accumulation of reaction products, the biological activity, and the prevailing conditions (for example, temperature and pressure). Reactions that involve the production or consumption of gases are often particularly influenced by pressure because of the high molar volume of gases. The effect of high total pressures on chemical reactions is generally to reduce or limit further gas generation.

Few data exist from which the ***Effects of Pressure on Microbial Gas Generation*** reactions that may occur in the WIPP can be assessed and quantified. Studies of microbial activity in deep-sea environments suggest (for example, Kato et al. 1994, p. 94) that microbial gas generation reactions are less likely to be limited by increasing pressures in the disposal rooms than are inorganic gas generation reactions (for example, corrosion). Consequently, the ***Effects of Pressure on Microbial Gas Generation*** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.3 FEP Number: W47
FEP Title: ***Effects of Radiation on Microbial Gas Generation***

SCR-6.5.1.3.1 Screening Decision: SO-C

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

SCR-6.5.1.3.2 Summary of New Information

The FEP screening argument has been updated to reflect the new radionuclide inventory, although the screening decision has not changed.

SCR-6.5.1.3.3 Screening Argument

Radiation may slow down microbial gas generation rates, but such an effect is not taken into account in WIPP PA calculations. According to the new *inventory* data, the total radionuclide inventory decreases from 7.44×10^6 (DOE 1996b) to 6.66×10^6 curies (Appendix DATA, Attachment F), about a 10 percent decrease Such a small change will not affect the original screening argument.

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

SCR-6.5.1.4 FEP Number: W49 and W51
FEP Title: ***Gasses from Metal Corrosion***
Chemical Effects of Corrosion

SCR-6.5.1.4.1 Screening Decision: UP

Gas generation from metal corrosion is accounted for in PA calculations, and the effects of chemical changes from metal corrosion are incorporated in the gas generation rates used.

SCR-6.5.1.4.2 Summary of New Information

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

SCR-6.5.1.4.3 Screening Argument

Oxic corrosion of waste drums and metallic waste will occur at early times following closure of the repository and will deplete its oxygen content. Anoxic corrosion will follow the oxic phase and will produce hydrogen, while consuming water. ***Gases from Metal Corrosion*** are accounted for in PA calculations.

The predominant ***Chemical Effect of Corrosion*** reactions on the environment of disposal rooms will be to lower the oxidation state of the brines and maintain reducing conditions.

Molecke (1979, p. 4) summarized gas generation rates that were observed during a range of experiments. The experiments were conducted over a range of temperatures and chemical conditions representing likely states within the repository. Later experiments reported by Telander and Westerman (1993) support the gas generation rate data reported by Molecke (1979). Their experiments investigated gas generation from corrosion under a wide range of possible conditions in the repository. The studies included corrosion of low-carbon steel waste packaging materials in synthetic brines, representative of intergranular Salado brines at the repository horizon, under anoxic (reducing) conditions.

Gas generation rates used in the PA calculations have been derived from available experimental data and are described in Section 6.4.3.3. The effects of chemical changes from metal corrosion are, therefore, accounted for in PA calculations.

SCR-6.5.1.5 FEP Number: W50
FEP Title: ***Galvanic Coupling*** (within the repository)

SCR-6.5.1.5.1 Screening Decision: SO-C

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

SCR-6.5.1.5.2 Summary of New Information

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

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

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

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

SCR-6.5.1.5.3 Screening Argument

Galvanic Coupling (i.e. establishing an electrical current through chemical processes) could lead to the propagation of electric potential gradients between metals in the waste form, canisters, and other metals external to the waste form, potentially influencing corrosion processes, gas generation rates and chemical migration.

Metallic ore bodies external to the repository are nonexistent (CCA Appendix GCR) and therefore galvanic coupling between the waste and metals external to the repository would not occur. However, a variety of metals will be present within the repository as waste metals and containers, creating a potential for formation of galvanic cells over short distances. As an example, the presence of copper could influence rates of hydrogen gas production resulting from the corrosion of iron. The interactions between metals depend upon their physical disposition and the prevailing solution conditions, including pH and salinity. Good physical and electrical contact between the metals is critical to the establishment of galvanic cells.

Consequently, given the preponderance of iron over other metals within the repository and the likely passivation of many nonferrous materials, the influence of these electrochemical interactions on corrosion, and therefore gas generation, is expected to be minimal. Therefore, the effects of ***Galvanic Coupling*** have been eliminated from PA calculations on the basis of low consequence.

SCR-6.5.1.6 FEP Number: W52
FEP Title: ***Radiolysis of Brine***

SCR-6.5.1.6.1 Screening Decision: SO-C

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

SCR-6.5.1.6.2 Summary of New Information

No new information is available relative to this FEP and screening decision. The screening argument has been modified for editorial purposes.

SCR-6.5.1.6.3 Screening Argument

Radiolysis of Brine in the WIPP disposal rooms, and of water in the waste, will lead to the production of gases and may significantly affect the oxygen content of the rooms. This in turn will affect the prevailing chemical conditions and potentially the concentrations of radionuclides that may be mobilized in the brines.

The overall reaction for the radiolysis of water in the waste and brine is

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

However, the production of intermediate oxygen-bearing species that may subsequently undergo reduction will lead to reduced oxygen gas yields. The remainder of this section is concerned with the physical effects of gas generation by radiolysis of brine.

Reed et al. (1993) studied radiolytic gas generation during experiments lasting between 155 and 182 days. These experiments involved both synthetic brines similar to those sampled from the Salado at the WIPP repository horizon, and brines occurring in reservoirs in the Castile, as well as real brines sampled from the Salado in the repository workings. The brines were spiked with ^{239}Pu(VI) at concentrations between 6.9×10^{-9} and 3.4×10^{-4} molal. During these relatively short-term experiments, hydrogen gas was observed as the product of radiolysis. Oxygen gas was not observed; this was attributed to the formation of intermediate oxygen-bearing species. However, given sufficient exposure to alpha-emission, oxygen production may reach 50 percent that of hydrogen.

An estimate of the potential rate of gas generation due to the radiolysis of brine, R_{RAD}, can be made by making the following assumptions:

- Gas production occurs following the reaction above, so that 1.5 moles of gas are generated for each mole of water consumed.
- Gas production occurs as a result of the alpha decay of ^{239}Pu.
- ^{239}Puconcentrations in the disposal room brines are controlled by solubility equilibria.

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

R_{RAD} is then given by

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

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

R	=	rate of gas production (moles per drum per year)
Y_g	=	radiolytic gas yield, in number of moles of gas produced per number of water molecules consumed
C_{Pu}	=	maximum dissolved concentration of plutonium (molar)
SA_{Pu}	=	specific activity of ^{239}Pu (5.42×10^{11} becquerels per mole)
$\overline{E}_{\alpha}$	=	average energy of α-particles emitted during ^{239}Pu decay (5.15×10^6 eV)
G	=	number of water molecules split per 100 eV of energy transferred from alpha-particles
V_B	=	volume of brine in the repository (liters)
N_D	=	number of CH drums in the repository (~8×10^5)
N_A	=	Avogadro constant (6.022×10^{23} molecules per mole)

The value of G used in this calculation has been set at 0.015, the upper limit of the range of values observed (0.011 to 0.015) during experimental studies of the effects of radiation on WIPP brines (Reed et al. 1993). A maximum estimate of the volume of brine that could potentially be present in the disposal region has been made from its excavated volume of 436,000 m^3 (520,266 yd^3). This estimate, in particular, is considered to be highly conservative because it makes no allowance for creep closure of the excavation, or for the volume of waste and backfill that will be emplaced, and takes no account of factors that may limit brine inflow. These parameter values lead to an estimate of the potential rate of gas production due to the ***Radiolysis of Brine*** of 0.6 moles per drum per year.

Assuming ideal gas behavior and repository conditions of 30°C (86°F) and 14.8 MPa (lithostatic pressure), this is equivalent to approximately 6.8×10^4 liters (1.8×10^4 gallons) per year.

Potential gas production rates from other processes that will occur in the repository are significantly greater than this. For example, under water-saturated conditions, microbial degradation of cellulosic waste has the potential to yield between 1.3×10^6 and 3.8×10^7 liters (3.4×10^5 and 1.0×10^7 gallons) per year; anoxic corrosion of steels has the potential to yield up to 6.3×10^5 liters (1.6×10^5 gallons) per year.

In addition to the assessment of the potential rate of gas generation by ***Radiolysis of Brine*** given above, a study of the likely consequences on disposal system performance has been undertaken by Vaughn et al. (1995). A model was implemented in BRAGFLO to estimate radiolytic gas generation in the disposal region according to the equation above.

A set of BRAGFLO simulations was performed to assess the magnitude of the influence of the ***Radiolysis of Brine*** on contaminant migration to the accessible environment. The calculations considered radiolysis of water by 15 isotopes of Th, Pu, U, and Am. Conditional complementary cumulative distribution functions (CCDFs) of normalized contaminated brine releases to the Culebra via a human intrusion borehole and the shaft system, as well as releases to the subsurface boundary of the accessible environment via the Salado interbeds, were constructed and compared to the corresponding baseline CCDFs calculated excluding radiolysis. The comparisons indicated that ***Radiolysis of Brine*** does not significantly affect releases to the Culebra or the subsurface boundary of the accessible environment under disturbed or undisturbed conditions (Vaughn et al. 1995). Although the analysis of Vaughn et al. (1995) used data that are different than those used in the PA calculations, estimates of total gas volumes in the repository are similar to those considered in the analysis performed by Vaughn et al. (1995).

Therefore, gas generation by ***Radiolysis of Brine*** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.1.7 FEP Number: W53
FEP Title: ***Radiolysis of Cellulose***

SCR-6.5.1.7.1 Screening Decision: SO-C

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

SCR-6.5.1.7.2 Summary of New Information

This FEP has been updated with new inventory data related to cellulose content. In addition, the screening argument has been modified by the inclusion of gas generation information from the WIPP transportation program.

SCR-6.5.1.7.3 Screening Argument

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

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

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

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

SCR-6.5.1.8 <u>FEP Number: W54</u>
<u>FEP Title: ***Helium Gas Production***</u>

SCR-6.5.1.8.1 Screening Decision: SO-C

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

SCR-6.5.1.8.2 Summary of New Information

The updated information for the WIPP disposal inventory indicates that the expected WIPP-scale radionuclide activity (2.48 million curies of TRU isotopes) is less than previously estimated in TWBIR Rev 3 (DOE 1996b). Thus, the ***Helium Gas Production*** argument for CRA-2004 is conservatively bounded by the previous CCA screening argument. The FEP screening argument and screening decision remain unchanged except for editorial changes.

SCR-6.5.1.8.3 Screening Argument

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

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

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

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

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

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

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

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

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

SCR-6.5.1.9 FEP Number: W55
FEP Title: ***Radioactive Gases***

SCR-6.5.1.9.1 Screening Decision: SO-C

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

SCR-6.5.1.9.2 Summary of New Information

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

SCR-6.5.1.9.3 Screening Argument

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

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

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

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

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

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

SCR-6.5.2 Speciation

SCR-6.5.2.1 FEP Number: W56
FEP Title: ***Speciation***

SCR-6.5.2.1.1 Screening Decision: UP – Disposal Room
UP – Culebra
SO-C – Beneficial – Shaft Seals

Chemical ***Speciation*** *is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms, and the degree of chemical retardation estimated during contaminant transport. The effects of cementitious seals on chemical* ***Speciation*** *have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.*

SCR-6.5.2.1.2 Summary of New Information

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

SCR-6.5.2.1.3 Screening Argument

Chemical ***Speciation*** refers to the form in which elements occur under a particular set of chemical or environmental conditions. Conditions affecting chemical ***Speciation*** include the temperature, pressure, and salinity (ionic strength) of the water in question. The importance of chemical speciation lies in its control of the geochemical reactions likely to occur and the consequences for actinide mobility.

SCR-6.5.2.1.3.1 *Disposal Room*

The concentrations of radionuclides that dissolve in any brines present in the disposal rooms after repository closure will depend on the stability of the chemical species that form under the prevailing conditions (for example, temperature, pressure, and ionic strength). The method used to derive radionuclide solubilities in the disposal rooms (see Section 6.4.3.5) considers the expected conditions. The MgO backfill will buffer pH values in the disposal room to between 9 and 10. Thus, chemical ***Speciation*** is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms.

SCR-6.5.2.1.3.2 *Repository Seals*

Certain repository materials have the potential to interact with groundwater and significantly alter the chemical ***Speciation*** of any radionuclides present. In particular, extensive use of cementitious materials in the seals may have the capacity to buffer groundwaters to extremely high pH (for example, Bennett et al. 1992, pp. 315 – 325). At high pH values, the ***Speciation*** and adsorption behavior of many radionuclides is such that their dissolved concentrations are reduced in comparison with near-neutral waters. This effect reduces the migration of radionuclides in dissolved form. The effects of cementitious seals on groundwater chemistry have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.2.1.3.3 *Culebra*

Chemical ***Speciation*** will affect actinide retardation in the Culebra. The dependence of actinide retardation on ***Speciation*** in the Culebra is accounted for in PA calculations by sampling over ranges of distribution coefficients (K_ds). The ranges of K_ds are based on the range of groundwater compositions and ***Speciation*** in the Culebra, including consideration of nonradionuclide solutes. The methodology used to simulate sorption in the Culebra is described in Section 6.4.6.2.1.

SCR-6.5.2.2 FEP Number: W57
FEP Title: ***Kinetics of Speciation***

SCR-6.5.2.2.1 Screening Decision: SO-C

The effects of reaction kinetics in chemical speciation reactions have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.5.2.2.2 Summary of New Information

No new information that would change the screening argument has arisen since the submission of the CCA. The original screening discussions have been edited for clarity of expression.

SCR-6.5.2.2.3 Screening Argument

Chemical ***Speciation*** of actinides describes the composition and relative distribution of dissolved species, such as the hydrated metal ion, or complexes, whether with organic or inorganic ligands. Conditions affecting chemical ***Speciation*** include temperature, ionic strength, ligand concentration and pH of the solution. Some ligands, such as hydroxide, may act to decrease actinide solubility, while others, such as citrate, frequently have the opposite influence, often increasing actinide solubility.

SCR-6.5.2.2.4 Disposal Room Equilibrium Conditions

The concentrations of radionuclides that can be dissolved in brines within the disposal rooms will depend on the thermodynamic stabilities and solubilities of the respective metal complexes. The Fracture-Matrix Transport (FMT) calculations and database input used to determine the brine solubilities of radionuclides takes into account the expected conditions, including temperature, ionic strength, pH, and ligand concentration. The chemical ***Speciation*** at equilibrium is accounted for in PA calculations in the estimates of radionuclide solubility in the disposal rooms.

SCR-6.5.2.2.5 Kinetics of Complex Formation

The waste that is emplaced within the WIPP contains radionuclides, including actinides or actinide bearing materials in solid phases, e.g. metal oxides, salts, coprecipitated solids, and contaminated objects. In the event of contact with brine, the solution phase concentration of dissolved radionuclides is controlled both by the solution composition, and by the kinetics of dissolution of the solid phases, effectively approaching equilibrium from undersaturation. Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonate and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and ethylene diamine tetra-acetate (EDTA) are kinetically very fast, reaching equilibrium in fractions of a second, an inconsequentially short time increment on the scale of the 10,000-year regulatory period. Reactions of these types are generally so fast that special techniques must be adopted to measure the reaction rates; as a practical matter, the reaction rate is limited by the mixing rate when metal solutions are combined with ligand solutions. As a result, the rate of approach to an equilibrium distribution of solution species takes place much more rapidly than dissolution, making the dissolution reaction the rate limiting step. The effects of reaction kinetics in aqueous systems are discussed by Lasaga et al. (1994) who suggest that in contrast to many heterogeneous reactions, homogeneous aqueous geochemical ***Speciation*** reactions involving relatively small inorganic species occur rapidly and are accurately described by thermodynamic equilibrium models that neglect explicit consideration of reaction kinetics.

For that reason, the rate at which solution species approach equilibrium distribution is of no consequence to repository performance. ***Kinetics of Chemical Speciation*** may be eliminated from PA calculations on the basis of no consequence.

SCR-6.5.3 Precipitation and Dissolution

SCR-6.5.3.1 FEP Number: W58, W59, and W60
FEP Title: ***Dissolution of Waste*** (W58)
Precipitation of Secondary Minerals (W59)
Kinetics of Precipitation and Dissolution (W60)

SCR-6.5.3.1.1 Screening Decision: UP – W58
SO-C Beneficial – W59
SO-C – W60

Waste dissolution and the release of radionuclides in the disposal rooms are accounted for in PA calculations. The formation of radionuclide bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The effect of reaction kinetics in controlling the rate of waste dissolution within the disposal rooms has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.3.1.2 Summary of New Information

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

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

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

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

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

SCR-6.5.3.1.3 Screening Argument

Dissolution of Waste and ***Precipitation of Secondary Minerals*** control the concentrations of radionuclides in brines and can influence rates of contaminant transport. Waste dissolution is accounted for in PA calculations. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

At low temperatures, precipitation and dissolution reactions are caused by changes in fluid chemistry that result in chemical undersaturation or oversaturation (Bruno and Sandino 1987). Precipitation can be divided into two stages: nucleation and crystal growth. Following nucleation, growth rates depend on the rates of surface processes and the transport of materials to the growth site. Mineral dissolution often depends on whether a surface reaction or transport of material away from the reaction site act as the rate controlling process. The former case may cause selective dissolution along crystallographically controlled features, whereas the latter may induce rapid bulk dissolution (Berner 1981). Thus, a range of kinetic behaviors will be exhibited by different mineral precipitation and dissolution reactions in geochemical systems.

SCR-6.5.3.1.3.1 *Disposal Room*

The waste that is emplaced within the WIPP contains radionuclides, including actinides or actinide-bearing materials in solid phases, e.g. metal oxides, salts, coprecipitated solids, and contaminated objects. In the event of contact with brine, the solution phase concentration of dissolved radionuclides is controlled both by the solution composition, and by the kinetics of dissolution of the solid phases, effectively approaching equilibrium from undersaturation. Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonated and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and EDTA are kinetically very fast, reaching equilibrium in less than one second, which is infinitesimally small on the time scale of the 10,000 year regulatory period. The rate at which thermodynamic equilibrium is approached between solution composition and the solubility controlling solid phases will be limited by rate of dissolution of the solid materials in the waste. As a result, until equilibrium is reached, the solution concentration of the actinides will be lower than the concentration that is predicted based upon equilibrium of the solution phase components with the solubility limiting solid phases. The WIPP actinide source term model, which describes interactions of the waste and brine, is described in detail in Section 6.4.3.5. The assumption of instantaneous equilibrium in waste dissolution reactions is a conservative approach, yielding maximum concentration estimates for radionuclides in the disposal rooms because a time weighted average resulting from a kinetically accurate estimate of solution compositions would have lower concentrations at early times. Waste dissolution at the thermodynamic equilibrium solubility limit is accounted for in PA calculations. However, the ***Kinetics of Dissolution*** within the disposal rooms has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.3.1.3.2 *Geological Units*

During groundwater flow, radionuclide precipitation processes that occur will lead to reduced contaminant transport. No credit is given in PA calculations to the potentially beneficial occurrence of ***Precipitation of Secondary Minerals***. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from PA calculations on the basis of beneficial consequence to disposal system performance. As a result ***Kinetics of Precipitation*** also has been eliminated from PA calculations because no credit is taken for precipitation reactions.

SCR-6.5.4 Sorption

SCR-6.5.4.1 FEP Number: W61, W62, and W63
FEP Title: ***Actinide Sorption*** (W61)
Kinetics of Sorption (W62)
Changes in Sorptive Surfaces (W63)

SCR-6.5.4.1.1 Screening Decision: UP – (W61, W62) In the Culebra & Dewey Lake
SO-C – Beneficial – (W61, W61) In the Disposal Room, Shaft Seals, Panel Closures, Other Geologic Units
UP – (W63)

Sorption within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of sorption processes in shaft seals and panel closures have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. Sorption within the Culebra and the Dewey Lake is accounted for in PA calculations. Sorption processes within other geological units of the *disposal system have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. Mobile adsorbents (for example, microbes and humic acids), and the sorption of radionuclides at their surfaces, are accounted for in PA calculations in the estimates of the concentrations of actinides that may be carried. The potential effects of reaction kinetics in adsorption processes and of* ***Changes in Sorptive Surfaces*** *are accounted for in PA calculations.*

SCR-6.5.4.1.2 Summary of New Information

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

SCR-6.5.4.1.3 Screening Argument

Sorption may be defined as the accumulation of matter at the interface between a solid and an aqueous solution. Within PA calculations, including those made for the WIPP, the use of isotherm representations of ***Actinide Sorption*** prevails because of their computational simplicity in comparison with other models (Serne 1992, pp. 238 – 239).

The mechanisms that control the ***Kinetics of Sorption*** processes are, in general, poorly understood. Often, sorption of inorganic ions on mineral surfaces is a two-step process consisting of a short period (typically minutes) of diffusion-controlled, rapid uptake, followed by slower processes (typically weeks to months) including surface rearrangement, aggregation and precipitation, and solid solution formation (Davis and Kent 1990, 202). Available data concerning rates of sorption reactions involving the important radionuclides indicate that, in general, a range of kinetic behavior is to be expected.

The relevance to the WIPP of sorption reaction kinetics lies in their effects on chemical transport. Sorption of waste contaminants to static surfaces of the disposal system such as seals and host rocks acts to retard chemical transport. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (nonequilibrium).

The following subsections discuss sorption in the disposal rooms, shaft seals, panel closures, the Culebra, and other geological units of the WIPP disposal system. Sorption on colloids, ***Microbes***, and particulate material is also discussed.

SCR-6.5.4.1.3.1 *Disposal Room*

The concentrations of radionuclides that dissolve in waters entering the disposal room will be controlled by a combination of sorption and dissolution reactions. However, because sorption processes are surface phenomena, the amount of material that is likely to be involved in sorption mass transfer processes will be small relative to that involved in the bulk dissolution of waste. WIPP PA calculations therefore assume that dissolution reactions control radionuclide concentrations. Sorption on waste, containers, and backfill within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4 Shaft Seals and Panel Closures

Chapter 3.0 and CCA Appendix SEAL describe the seals that are to be placed at various locations in the access shafts and waste panel access tunnels. The materials to be used include crushed salt, bentonite clay, and cementitious grouts. Of these, the latter two in particular possess significant sorption capacities. No credit is given for the influence of sorption processes that may occur in seal materials and their likely beneficial effects on radionuclide migration rates. The effects of sorption processes in shaft seals and panel closures have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4.1 *Culebra*

Sorption within the Culebra is accounted for in PA calculations as discussed in Section 6.4.6.2. The model used comprises an equilibrium, sorption isotherm approximation, employing constructed cumulative distribution functions (CDFs) of distribution coefficients (K_ds) applicable to dolomite in the Culebra. The potential effects of reaction kinetics in adsorption processes are encompassed in the ranges of K_ds used. The geochemical speciation of the Culebra groundwaters and the effects of ***Changes in Sorptive Surfaces*** are implicitly accounted for in PA calculations for the WIPP in the ranges of K_ds used.

SCR-6.5.4.1.4.2 *Other Geological Units*

During groundwater flow, any radionuclide sorption processes that occur between dissolved or colloidal actinides and rock surfaces will lead to reduced rates of contaminant transport. The sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter it from being released to the accessible environment over 10,000 years (Wallace et al. 1995). Thus, sorption within the Dewey Lake is accounted for in PA calculations as discussed in Section 6.4.6.6. No credit is given to the potentially beneficial occurrence of sorption in other geological units outside the Culebra. Sorption processes within other geological units of the disposal system have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.5.4.1.4.3 *Sorption on Colloids, Microbes, and Particulate Material*

The interactions of sorption processes with colloidal, microbial, or particulate transport are complex. Neglecting sorption of contaminants on immobile surfaces in the repository shafts and Salado (for example, the clays of the Salado interbeds) is a conservative approach because it leads to overestimated transport rates. However, neglecting sorption on potentially mobile adsorbents (for example, microbes and humic acids) cannot be shown to be conservative with respect to potential releases, because mobile adsorbents may act to transport radionuclides sorbed to them. Consequently, the concentrations of actinides that may be carried by mobile adsorbents are accounted for in PA calculations (see Section 6.4.3.6).

SCR-6.5.5 Reduction-Oxidation Chemistry

SCR-6.5.5.1 FEP Number: W64 and W66
FEP Title: ***Effects of Metal Corrosion***
Reduction-Oxidation Kinetics

SCR-6.5.5.1.1 Screening Decision: UP

The effects of reduction-oxidation reactions related to metal corrosion on reduction-oxidation conditions are accounted for in PA calculations. Reduction-oxidation reaction kinetics are accounted for in PA calculations.

SCR-6.5.5.1.2 Summary of New Information

No new information has been identified for these FEPs. The screening arguments have not changed. Editorial changes have been made to the discussion.

SCR-6.5.5.1.3 Screening Argument

SCR-6.5.5.1.3.1 *Reduction-Oxidation Kinetics*

In general, investigation of the reduction-oxidation couples present in aqueous geochemical systems suggests that most reduction-oxidation reactions are not in thermodynamic equilibrium (Wolery 1992, 27). The lack of data characterizing the rates of reactions among trace element reduction-oxidation couples leads to uncertainty in elemental speciation. This uncertainty in ***Reduction-Oxidation Kinetics*** is accounted for in PA calculations in the dissolved actinide source term model (see Section 6.4.3.5), which estimates the probabilities that particular actinides occur in certain oxidation states.

SCR-6.5.5.1.3.2 *Corrosion*

Other than gas generation, which is discussed in FEPs W44 through W55, the main ***Effect of Metal Corrosion*** will be to influence the chemical conditions that prevail within the repository. Ferrous metals will be the most abundant metals in the WIPP, and these will corrode on contact with any brines entering the repository. Initially, corrosion will occur under oxic conditions owing to the atmospheric oxygen present in the repository at the time of closure. However, consumption of the available oxygen by corrosion reactions will rapidly lead to anoxic (reducing) conditions. These changes and controls on conditions within the repository will affect the chemical ***Speciation*** of the brines and may affect the oxidation states of the actinides present. Changes to the oxidation states of the actinides will lead to changes in the concentrations that may be mobilized during brine flow. The oxidation states of the actinides are accounted for in PA calculations by the use of parameters that describe probabilities that the actinides exist in particular oxidation states and, as a result, the likely actinide concentrations. Therefore, the ***Effect of Metal Corrosion*** are accounted for in PA calculations.

SCR-6.5.5.2 FEP Number: W65
FEP Title: ***Reduction-Oxidation Fronts***

SCR-6.5.5.2.1 Screening Dec*ision: SO-P*

The migration of ***Reduction-Oxidation Fronts*** *through the repository has been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.*

SCR-6.5.5.2.2 Summary of New Information

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

SCR-6.5.5.2.3 Screening Argument

The development of ***Reduction-Oxidation Fronts*** in the disposal system may affect the chemistry and migration of radionuclides. ***Reduction-Oxidation Fronts*** separate regions that may be characterized, in broad terms, as having different oxidation potentials. On either side of a ***Reduction-Oxidation Fronts***, the behavior of reduction-oxidation-sensitive elements may be controlled by different geochemical reactions. Elements that exhibit the greatest range of oxidation states (for example, uranium, neptunium, and plutonium) will be the most affected by ***Reduction-Oxidation Fronts*** development and migration. The migration of ***Reduction-Oxidation Fronts*** may occur as a result of diffusion processes, or in response to groundwater flow, but will be restricted by the occurrence of heterogeneous buffering reactions (for example, mineral dissolution and precipitation reactions). Indeed, these buffering reactions cause the typically sharp, distinct nature of reduction-oxidation fronts.

Of greater significance is the possibility that the flow of fluids having different oxidation potentials from those established within the repository might lead to the development and migration of a large-scale ***Reduction-Oxidation Fronts***. ***Reduction-Oxidation Fronts*** have been observed in natural systems to be the loci for both the mobilization and concentration of radionuclides, such as uranium. For example, during investigations at two uranium deposits at Poços de Caldas, Brazil, uranium was observed by Waber (1991) to be concentrated along ***Reduction-Oxidation Fronts*** at the onset of reducing conditions by its precipitation as uranium oxide. In contrast, studies of the Alligator Rivers uranium deposit in Australia by Snelling (1992) indicated that the movement of the relatively oxidized weathered zone downwards through the primary ore body as the deposit was eroded and gradually exhumed led to the formation of secondary uranyl-silicate minerals and the mobilization of uranium in its more soluble uranium (VI) form in near-surface waters. The geochemical evidence from these sites suggests that the ***Reduction-Oxidation Fronts*** had migrated only slowly, at most on the order of a few tens of meters per million years. These rates of migration were controlled by a range of factors, including the rates of erosion, infiltration of oxidizing waters, geochemical reactions, and diffusion processes.

The migration of large-scale ***Reduction-Oxidation Fronts*** through the repository as a result of regional fluid flow is considered unlikely over the regulatory period on the basis of comparison with the slow rates of ***Reduction-Oxidation Fronts*** migration suggested by natural system studies. This comparison is considered conservative because the relatively impermeable nature of the Salado suggests that ***Reduction-Oxidation Fronts*** migration rates at the WIPP are likely to be slower than those observed in the more permeable lithologies of the natural systems studied. Large-scale ***Reduction-Oxidation Fronts*** have therefore been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.

SCR-6.5.5.3 FEP Number: W67
FEP Title: ***Localized Reducing Zones***

SCR-6.5.5.3.1 Screening Decision: SO-C

*The formation of **Localized Reducing Zones** has been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

SCR-6.5.5.3.2 Summary of New Information

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

SCR-6.5.5.3.3 Screening Argument

The dominant reduction reactions in the repository include steel corrosion and microbial degradation. The following bounding calculation shows that molecular diffusion alone will be sufficient to mix brine chemistry over a distance of meters and therefore the formation of ***Localized Reducing Zones*** in the repository is of low consequence.

The diffusion of a chemical species in a porous medium can be described by Fick's equation (e.g., Richardson and McSween 1989, p.132):

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

where C is the concentration of the diffusing chemical species; t is the time; X is the distance; and D_{eff} is the effective diffusivity of the chemical species in a given porous medium. D_{eff} is related to the porosity (ϕ) of the medium by (e.g., Oelkers, 1996):

$$D_{eff} = \phi^2 D \tag{18}$$

where D is the diffusivity of the species in pure solution. The D values for most aqueous species at room temperatures fall into a narrow range, and 10^{-5} cm^2 (1.5×10^{-6} in^2) per second is a good approximation (e.g., Richardson and McSween 1989, p.138). From the WIPP PA calculations (Bean et al. 1996, p.7-29; WIPP PA Department, 1993, Equation B-8), the porosity in the WIPP waste panels after room closure is calculated to be 0.4 to 0.7. From Equation (19), the effective diffusivity D_{eff} in the waste is estimated to be $2 \sim 5 \times 10^{-6}$ cm^2 (7×10^{-7} in^2) per second (= $6 \sim 16 \times 10^{-3}$ m^2/year).

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

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

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

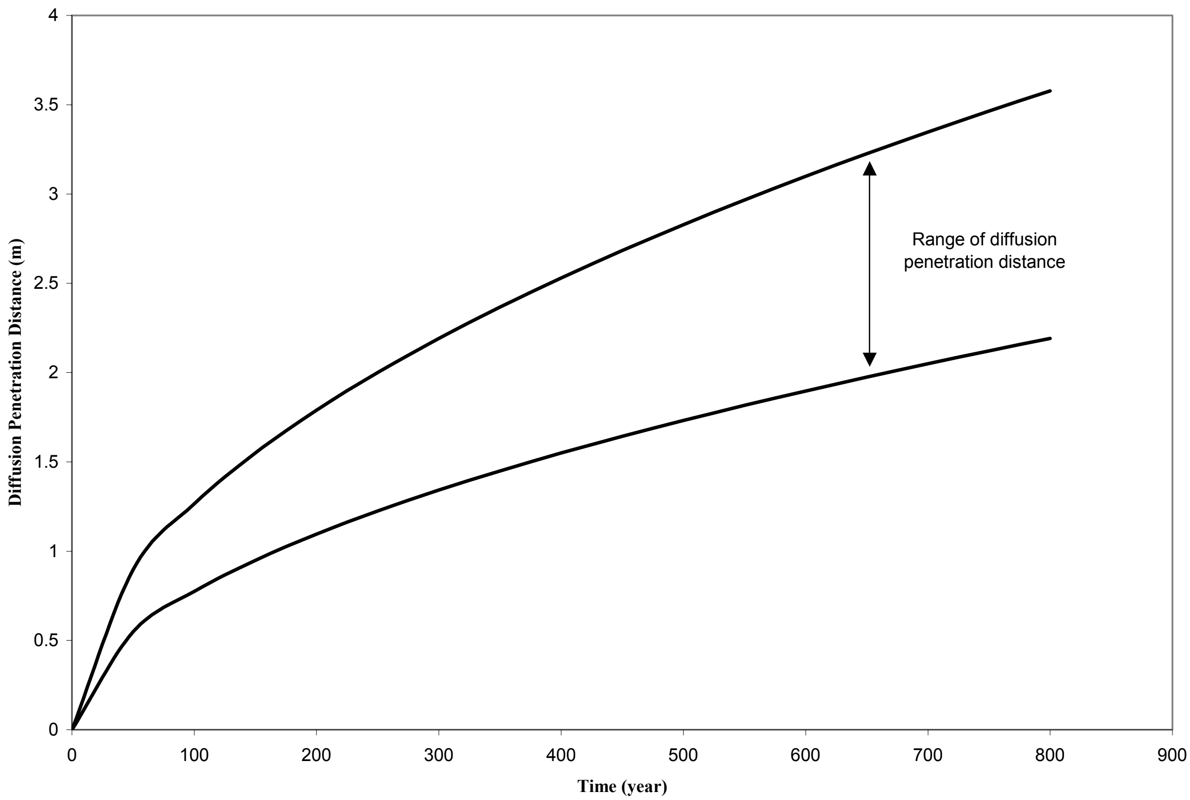

Figure SCR-1. Diffusion Penetration Distance in the WIPP as a Function of Diffusion Time

Direct brine release requires the repository gas pressure to be at least 8 MPA (Stoelzel et al. 1996). The CRA calculations show that it will take at least 100 years for the repository pressure to reach this critical value by gas generation processes. Over this time scale, according to Equation (20) and Figure SCR-1, molecular diffusion alone can mix brine composition effectively at least over a distance of ~ 1 m (3.3 ft).

The above calculation assumes diffusion only through liquid water. This assumption is applicable to steel corrosion, the humid rate of which is zero. Note that microbial reactions can also consume or release gaseous species. The diffusion of a gaseous species is much faster than an aqueous one. Thus, molecular diffusion can homogenize microbial reactions even at a much large scale.

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

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

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

SCR-6.5.6 Organic Complexation

SCR-6.5.6.1 FEP Number: W68, W69, and W71
FEP Title: ***Organic Complexation*** (W68)
Organic Ligands (W69)
Kinetics of Organic Complexation (W71)

SCR-6.5.6.1.1 Screening Decision: UP W68 and W69
SO-C W71

*The effects of anthropogenic **Organic Complexation** reactions, including the effects of **Organic Ligands**, humic, and fulvic acids, have been incorporated in the PA calculations. The kinetics of organic ligand complexation is screened out because the rate at which **Organic Ligands** are complexed to actinide is so fast that it has no consequence to repository performance.*

SCR-6.5.6.1.2 Summary of New Information

The ***Organic Complexation*** was screened out for the CCA PA, on the basis that transition metals (in particular **iron**, **nickel**, **chromium**, **vanadium**, and **manganese**, present in waste drum steel) would compete effectively with the actinides for the binding sites on the organic ligands, thus preventing significant complexation of actinides organics. Although the CRA-2004 calculations include the effects of ***Organic Ligands*** (acetate, citrate, EDTA, and oxalate) on actinide solubility calculations, based on a revised thermodynamic database, the rate at which ***Organic Ligands*** are complexed to actinides is of no consequence to repository performance. Kinetics of ***Organic Ligands*** complexation may be eliminated from PA calculations on the basis of no consequence.

SCR-6.5.6.1.3 Screening Argument

From a PA standpoint, the most important actinides are Th, U, Np, Pu, and Am. Dissolved thorium, uranium, neptunium, plutonium, and americium will speciate essentially entirely as Th(IV), U(IV) or U(VI), Np(IV) or Np(V), Pu(III) or Pu(IV), and Am(III) under the strongly reducing conditions expected due to the presence of Fe(II) and microbes. (Section SOTERM-33 – SOTERM-36).

Some ***Organic Ligands*** can increase the actinide solubilities. An estimate of the complexing agents in the transuranic solidified waste forms scheduled for disposal in WIPP is presented in Appendix DATA, Attachment F Table DATA-F-3.2-24. Acetate, citrate, oxalate, and EDTA were determined to be the only water-soluble and actinide complexing organic ligands present in significant quantities in the TWBIR. These ligands and their complexation with actinides (Th(IV), U(VI), Np(V), and Am(III)) in a variety of ionic strength media were studied at Florida State University (FSU) (Choppin et al. 2001). The FSU studies showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved actinide concentrations. Lactate behavior was also studied at FSU because it appeared in the preliminary inventory of nonradioactive constituents of the TRU waste to be emplaced in the WIPP (Brush 1990); lactate did not appear in the TWBIR, nor does it appear in the 2003 update to the TWBIR (Appendix DATA, Attachment F).

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

- Although the FSU experimental work on ***Organic Ligands*** complexation showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved actinide concentrations, SNL did not include the results in the FMT calculations for the CCA PA because (1) the thermodynamic database for ***Organic Complexation*** of actinides was not considered adequate at the time, and (2) side-calculations using thermodynamic data for low-ionic-strength NaCl solutions showed that transition metals (in particular iron, nickel, chromium, vanadium, and manganese present in waste drum steel) would compete effectively with the actinides for the binding sites on the ***Organic Ligands***, thus preventing significant complexation of actinides organics (Appendix PA, Attachment SOTERM , Sections SOTERM-36 - SOTERM-41).

The CRA-2004 calculations include the effects of organic ligands (acetate, citrate, EDTA, and oxalate) on actinide solubilities in the FMT calculations (Brush and Xiong 2003). The FMT database includes all of the results of experimental studies (Choppin et al. 2001) required to predict the complexation of dissolved An(III), An(IV), and An(V) species by acetate, citrate, EDTA, and oxalate (Giambalvo 2002a, ***2002***b).

Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonate and hydroxide, and with organic ligands, such as acetate, citrate, oxalate, and EDTA, are kinetically very fast, reaching equilibrium in fractions of a second, an inconsequentially short time increment on the scale of the 10,000-year regulatory period. Reactions of these types are generally so fast that special techniques must be adopted to measure the reaction rates; as a practical matter, the reaction rate is limited by the mixing rate when metal solutions are combined with ligand solutions.

For that reason, the rate at which ***Organic Ligands*** are complexed to actinide is of no consequence to repository performance. ***Kinetics of Organic Complexation*** may be eliminated from PA calculations on the basis of no consequence.

SCR-6.5.6.2 FEP Number: W70
FEP Title: ***Humic and Fulvic Acids***

SCR-6.5.6.2.1 Screening Decision: UP

*The presence of **Humic and Fulvic Acids** is incorporated in PA calculations.*

SCR-6.5.6.2.2 Summary of New Information

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

SCR-6.5.6.2.3 Screening Argument

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

SCR-6.5.7 Chemical Effects on Material Properties

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

SCR-6.5.7.1.1 Screening Decision: UP

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

SCR-6.5.7.1.2 Summary of New Information

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

SCR-6.5.7.1.3 Screening Argument

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

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

SCR-6.5.7.2 FEP Number: W75
FEP Title: ***Chemical Degradation of Backfill***

SCR-6.5.7.2.1 Screening Decision: SO-C

The effects on material properties of the ***Chemical Degradation of Backfill*** *have been eliminated from PA calculations on the basis of low consequence.*

SCR-6.5.7.2.2 Summary of New Information

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

SCR-6.5.7.2.3 Screening Argument

Degradation of the chemical conditioners or backfill added to the disposal room is a prerequisite of their function in buffering the chemical environment of the disposal room. However, the chemical reactions (Snider 2001) and dissolution involved will change the physical properties of the material. Because the mechanical and hydraulic characteristics of the backfill have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system, the effects of the ***Chemical Degradation of Backfill*** on material properties have been eliminated from PA calculations on the same basis.

SCR-6.6 Contaminant Transport Mode Features, Events, and Processes

SCR-6.6.1 Solute and Colloid Transport

SCR-6.6.1.1 FEP Number: W77
FEP Title: ***Solute Transport***

SCR-6.6.1.1.1 Screening Decision: UP

Transport of dissolved radionuclides is accounted for in PA calculations.

SCR-6.6.1.1.2 Summary of New Information

No new information has been identified for this FEP. Since this FEP is accounted for (UP) in PA, the implementation may differ from that used in the CCA, although the screening decision has not changed. Changes in implementation (if any) are described in Sections 6.4.5.4 and 6.4.6.2.1.

SCR-6.6.1.1.3 Screening Argument

Solute Transport may occur by advection, dispersion, and diffusion down chemical potential gradients, and is accounted for in PA calculations (Sections 6.4.5.4 and 6.4.6.2.1).

SCR-6.6.1.2 FEP Number: W78, W79, W80, and W81
FEP Title: ***Colloidal Transport*** (W78)
Colloidal Formation and Stability (W79)
Colloidal Filtration (W80)
Colloidal Sorption (W81)

SCR-6.6.1.2.1 Screening Decision: UP

Formation of colloids, transport of colloidal radionuclides, and colloid retardation through filtration and sorption are accounted for in PA calculations.

SCR-6.6.1.2.2 Summary of New Information

No new information has been identified for these FEPs. Since these FEPs are accounted for (UP) in PA, the implementation may differ from that used in the CCA, however the screening decision has not changed. Changes in implementation (if any) are described in Sections 6.4.3.6 and 6.4.6.2.2.

SCR-6.6.1.2.3 Screening Argument

Colloids typically have sizes of between 1 nm and 1 µm and may form stable dispersions in groundwaters. ***Colloid Formation and Stability*** depends on their composition and the prevailing chemical conditions (for example, salinity). Depending on their size, ***Colloid Transport*** may occur at different rates than those of fully dissolved species. They may be physically excluded from fine porous media, and their migration may be accelerated through fractured media in channels where velocities are greatest. However, they can also interact with the host rocks during transport and become retarded. These interactions may be of a chemical or physical nature and include electrostatic effects, leading to ***Colloid Sorption*****,** and sieving leading to ***Colloid Filtration*** and pore blocking. ***Colloid Formation and Stability*** is accounted for in PA calculations through estimates of colloid numbers in the disposal room based on the prevailing chemical conditions (Section 6.4.3.6). Colloid sorption, filtration, and transport in the Culebra are accounted for in PA calculations (Section 6.4.6.2.2).

SCR-6.6.2 Particle Transport

SCR-6.6.2.1 FEP Number: W82, W83,W84, W85, and W86
FEP Title: ***Suspension of Particles*** (W82)
Rinse (W83)
Cuttings (W84)
Cavings (W85)
Spallings (W86)

SCR-6.6.2.1.1 Screening Decision: DP W82, W84, W85, W86
SO-C W83

The formation of particulates through **Rinse** *and subsequent transport of radionuclides in groundwater and brine has been eliminated from PA calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system. The transport of radionuclides as particulates (**Cuttings, Cavings**, and **Spallings**) during penetration of the repository by a borehole, is accounted for in PA calculations.*

SCR-6.6.2.1.2 Summary of New Information

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

SCR-6.6.2.1.3 Screening Argument

Suspensions of Particles that have sizes larger than colloids are unstable because the particles undergo gravitational settling. It is unlikely that brine flow will be rapid enough within the WIPP disposal rooms to generate particulate suspensions through **Rinse** and transport under undisturbed conditions. Mobilization of suspensions would effect a local and minor redistribution of radionuclides within the room and would not result in increased radionuclide transport from the repository. The formation of particulates through **Rinse** and transport of radionuclides in groundwater and brine has been eliminated from PA calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system.

Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (FEPs H21 and H23). This waste could include material intersected by the drill bit (***Cuttings***), material eroded from the borehole wall by circulating drilling fluid (***Cavings***), and material that enters the borehole as the repository depressurizes (***Spallings***). Transport of radionuclides by these materials and in brine is accounted for in PA calculations and is discussed in Section 6.4.7.1.

SCR-6.6.3 Microbial Transport

SCR-6.6.3.1 FEP Number: W87
FEP Title: ***Microbial Transport***

SCR-6.6.3.1.1 Screening Decision: UP

Transport of radionuclides bound to microbes is accounted for in PA calculations.

SCR-6.6.3.1.2 Summary of New Information

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

SCR-6.6.3.1.3 Screening Argument

Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system. Because of their colloidal size, microbes, and any radionuclides bound to them, may be transported at different rates than radionuclides in solution. ***Microbial Transport*** of radionuclides is accounted for in PA calculations (Section 6.4.6.2.2).

SCR-6.6.3.2 FEP Number: W88
FEP Title: ***Biofilms***

SCR-6.6.3.2.1 Screening Decision: SO-C Beneficial

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

SCR-6.6.3.2.2 Summary of New Information

The effects of ***Biofilms*** on ***Microbial Transport*** have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system. The discussion of this FEP has been updated with recent experimental work.

SCR-6.6.3.2.3 Screening Argument

Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system.

Biofilms may influence microbial and radionuclide transport rates through their capacity to retain, and therefore retard, both the microbes themselves and radionuclides. The formation of ***Biofilms*** in deep subsurface environments such as in the WIPP is controversial. Since the microbial degradation experiments at Brookhaven National Laboratory (BNL) bracket expected repository conditions, the potential effect of ***Biofilms*** formation on microbial degradation and transport, if any, has been captured in the PA parameters derived from those experiments

(Francis and Gillow 1994; Francis et. al 1997; Francis and Gillow 2000; Gillow and Francis 2001a; Gillow and Francis 2001b; Gillow and Francis 2002a; Gillow and Francis 2002b). As a matter of fact, no apparent formation of stable biofilms was observed in the BNL experiments. The formation of ***Biofilms*** tends to reduce cell suspension and mobility. This effect has been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.6.4 Gas Transport

SCR-6.6.4.1 FEP Number: W89
FEP Title: ***Transport of Radioactive Gases***

SCR-6.6.4.1.1 Screening Decision: SO-C

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

SCR-6.6.4.1.2 Summary of New Information

This FEP discussion has been updated to include recent inventory information. The screening decision has not changed.

SCR-6.6.4.1.3 Screening Argument

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

SCR-6.7 Contaminant Transport Processes

SCR-6.7.1 Advection

SCR-6.7.1.1 FEP Number: W90
FEP Title: ***Advection***

SCR-6.7.1.1.1 Screening Decision: UP

Advection *of contaminants is accounted for in PA calculations.*

SCR-6.7.1.1.2 Summary of New Information

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

SCR-6.7.1.1.3 Screening Argument

Advection (that is, the transport of dissolved and solid material by flowing fluid) is accounted for in PA calculations (Sections 6.4.5.4 and 6.4.6.2).

SCR-6.7.2 Diffusion

SCR-6.7.2.1 FEP Number: W91 and W92
FEP Title: ***Diffusion*** (W91)
Matrix Diffusion (W92)

SCR-6.7.2.1.1 Screening Decision: UP

Diffusion *of contaminants and retardation by* ***Matrix Diffusion*** *are accounted for in PA calculations.*

SCR-6.7.2.1.2 Summary of New Information

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

SCR-6.7.2.1.3 Screening Argument

Diffusion (that is, the movement of molecules or particles both parallel to and transverse to the direction of advection in response to Brownian forces) and, more specifically ***matrix diffusion***, whereby movement is transverse to the direction of advection within a fracture and into the surrounding rock matrix, are accounted for in PA calculations (Section 6.4.6.2).

SCR-6.7.3 Thermochemical Transport Phenomena

SCR-6.7.3.1 FEP Number: W93
FEP Title: ***Soret Effect***

SCR-6.7.3.1.1 Screening Decision: SO-C

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

SCR-6.7.3.1.2 Summary of New Information

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

SCR-6.7.3.1.3 Screening Argument

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

$$J = - DVC - NDVT, \tag{21}$$

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

$$N = S_T C(1-C), \tag{22}$$

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

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

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

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

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

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

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

If the repository were to be inundated following a drilling intrusion, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (10.8°F). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6°C (10.8°F) represents the maximum that could occur as a result of a combination of exothermic reactions occurring simultaneously. Temperature increases of this magnitude will not result in significant Soret diffusion within the disposal system.

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

SCR-6.7.4 Electrochemical Transport Phenomena

SCR-6.7.4.1 FEP Number: W94
FEP Title: ***Electrochemical Effects***

SCR-6.7.4.1.1 Screening Decision: SO-C

The effects of electrochemical transport phenomena caused by electrochemical reactions have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.4.1.2 Summary of New Information

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

SCR-6.7.4.1.3 Screening Argument

The variety of waste metals and metal packaging in the repository may allow galvanic cells spanning short distances to be established. The interactions among the metals depend upon their physical characteristics and the chemical conditions in the repository. For example, good physical and electrical contact, which is critical to the establishment of galvanic cells, may be impeded by electrically nonconductive waste materials. Additionally, in order to establish a galvanic cell, it is necessary that the metals have different values for standard reduction potentials. For example, a galvanic cell is not expected to be formed by contact of two segments of metals with identical compositions. As a result, galvanic cells can only be established by contact of dissimilar metals, as might happen due to contact between a waste drum and the contents, or between contents within a waste package. The localized nature of electrochemical transport is restricted to the size scale over which galvanic cells can develop, i.e., on the order of size of waste packages. Since the possible range of transport is restricted by the physical extent of galvanic activity, ***Electrochemical Effects*** cannot act as long-range transport mechanisms for radionuclides and therefore are of no consequence to the performance of the repository.

SCR-6.7.4.2 FEP Number: W95
FEP Title: ***Galvanic Coupling***

SCR-6.7.4.2.1 Screening Decision: SO-P

*The effects of **Galvanic Coupling** between the waste and metals external to the repository on transport have been eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.*

SCR-6.7.4.2.2 Summary of New Information

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

SCR-6.7.4.2.3 Screening Argument

With regard to the WIPP, ***Galvanic Coupling*** refers to the establishment of galvanic cells between metals in the waste form, canisters, and other metals external to the waste form.

Long range electric potential gradients may exist in the subsurface as a result of groundwater flow and electrochemical reactions. The development of electric potential gradients may be associated with the weathering of sulfide ore bodies, variations in rock properties at geological contacts, bioelectric activity associated with organic matter, natural corrosion reactions, and temperature gradients in groundwater. With the exception of mineralization potentials associated with metal sulfide ores, the magnitude of electric potentials is usually less than about 100 millivolts and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976). Metals external to the waste form can include natural metallic ore bodies in the host rock. However, metallic ore bodies and metallic sulfide ores do not exist in the region of the repository (CCA Appendix GCR). As a result, galvanic coupling between the waste and metallic materials outside the repository cannot occur. Therefore, ***Galvanic Coupling*** is eliminated from PA calculations on the basis of low probability of occurrence over 10,000 years.

SCR-6.7.4.3 FEP Number: W96
FEP Title: ***Electrophoresis***

SCR-6.7.4.3.1 Screening Decision: SO-C

*The effects of electrochemical transport phenomena caused by **Electrophoresis** have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.*

SCR-6.7.4.3.2 Summary of New Information

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

SCR-6.7.4.3.3 Screening Argument

Long range (in terms of distance) electric potential gradients may exist in the subsurface as a result of groundwater flow and electrochemical reactions. The development of potentials may be associated with the weathering of sulfide ore bodies, variations in rock properties at geological contacts, bioelectric activity associated with organic matter, natural corrosion reactions, and temperature gradients in groundwater. With the exception of mineralization potentials associated with metal sulfide ores, the magnitude of such potentials is usually less than about 100 millivolts and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976, p. 458). Short range potential gradients due to corrosion of metals within the waste may be set up over distances that are restricted to the size scale of the waste packages.

A variety of metals will be present within the repository as waste metals and metal packaging, which may allow electrochemical cells to be established over short distances. The types of interactions that will occur depend on the metals involved, their physical characteristics, and the prevailing solution conditions. Electrochemical cells that may be established will be small relative to the size of the repository, limiting the extent to which migration of contaminants by ***Electrophoresis*** can occur. The electric field gradients will be of small magnitude and confined to regions of electrochemical activity in the area immediately surrounding the waste material. As a result, ***Electrophoretic Effects*** on migration behavior due to both long and short range potential gradients have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5 Physiochemical Transport Phenomena

SCR-6.7.5.1 FEP Number: W97
FEP Title: ***Chemical Gradients***

SCR-6.7.5.1.1 Screening Decision: SO-C

*The effects of enhanced diffusion across **Chemical Gradients** have been eliminated from PAs on the basis of low consequence to the performance of the disposal system.*

SCR-6.7.5.1.2 Summary of New Information

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

SCR-6.7.5.1.3 Screening Argument

Chemical Gradients within the disposal system, whether induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants. Gradients will exist at interfaces between different repository materials and between repository and geological materials. Distinct chemical regimes will be established within concrete seals and adjoining host rocks. Similarly, ***Chemical Gradients*** will exist between the waste and the surrounding rocks of the Salado. Other ***Chemical Gradients*** may exist due to the juxtaposition of relatively dilute groundwaters and brines or between groundwaters with different compositions. Natural gradients currently exist between different groundwaters in the Culebra.

Enhanced diffusion is a possible consequence of ***Chemical Gradients*** that occur at material boundaries. However, the distances over which enhanced diffusion could occur will be small in comparison to the size of the disposal system. Processes that may be induced by ***Chemical Gradients*** at material boundaries include the formation or destabilization of colloids. For example, cementitious materials that will be emplaced in the WIPP as part of the waste and the seals contain colloidal-sized materials, such as calcium-silicate-hydrate gels, and alkaline pore fluids. ***Chemical Gradients*** will exist between the pore fluids in the cementitious materials and the less alkaline surroundings. Chemical interactions at these interfaces may lead to the generation of colloids of the inorganic, mineral fragment type. Colloidal compositions may include calcium and magnesium oxides, calcium hydroxide, calcium-aluminum silicates, calcium-silicate-hydrate gels, and silica. Experimental investigations of the stability of inorganic, mineral fragment colloidal dispersions have been carried out as part of the WIPP colloid-facilitated actinide transport program (Papenguth and Behl 1996). Results of the investigations indicate that the salinities of the WIPP brines are sufficient to cause destabilization of mineral fragment colloidal dispersions. Therefore, concentrations of colloidal suspensions originating from concrete within the repository are expected to be extremely low, and are considered in PA calculations.

SCR-6.7.5.2 FEP Number: W98
FEP Title: ***Osmotic Processes***

SCR-6.7.5.2.1 Screening Decision: SO-C

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

SCR-6.7.5.2.2 Summary of New Information

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

SCR-6.7.5.2.3 Screening Argument

Osmotic Processes, i.e., diffusion of water through a semi permeable or differentially permeable membrane in response to a concentration gradient, may occur at interfaces between waters of different salinities. ***Osmotic Processes*** can occur if waters of different salinities and/or compositions exist on either side of a particular lithology such as clay, or a lithological boundary that behaves as a semipermeable membrane. At the WIPP, clay layers within the Salado may act as semi permeable membranes across which ***Osmotic Processes*** may occur.

In the absence of a semipermeable membrane, water will move from the more dilute water into the more saline water. However, the migration of dissolved contaminants across an interface may be restricted depending upon the nature of the membrane. A hydrological gradient across a semi permeable membrane may either enhance or oppose water movement by osmosis depending on the direction and magnitude of the gradient. Dissolved contaminants that cannot pass through a semi-permeable membrane may be moved towards the membrane and concentrated along the interface when advection dominates over osmosis and reverse osmosis occurs. Thus, both osmosis and reverse osmosis can restrict the migration of dissolved contaminants and possibly lead to concentration along interfaces between different water bodies. The effects of ***Osmotic Processes*** have been eliminated from PA calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR-6.7.5.3 FEP Number: W99
FEP Title: ***Alpha Recoil***

SCR-6.7.5.3.1 Screening Decision: SO-C

*The effects of **Alpha-Recoil Processes** on radionuclide transport have been eliminated from PA calculations on the basis of low consequence to performance of the disposal system.*

SCR-6.7.5.3.2 Summary of New Information

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

SCR-6.7.5.3.3 Screening Argument

Alpha particles are emitted with sufficiently high energies that daughter nuclides recoil appreciably to conserve system momentum. For example, ^{238}U decays to ^{234}Th with emission of a 4.1 MeV alpha particle. The law of conservation of momentum requires that the daughter nuclide, ^{234}Th, recoils in the opposite direction with an energy of approximately 0.07 MeV. The energy is great enough to break chemical bonds or cause ^{234}Th to move a short distance through a crystal lattice. If the ^{234}Th is close enough to the surface of the crystal, it will be ejected into the surroundings. ^{234}Th decays to ^{234}Pa which decays to ^{234}U with respective half-lives of 24.1 days and 1.17 minutes. The recoil and decay processes can lead to the apparent preferential dissolution or leaching of ^{234}U relative to ^{238}U from crystal structures and amorphous or adsorbed phases. Preferential leaching may be enhanced due to radiation damage to the host phase resulting from earlier radioactive decay events. Consequently, ^{234}U sometimes exhibits enhanced transport behavior relative to ^{238}U.

The influence of ***Alpha-Recoil*** processes on radionuclide transport through natural geologic media is dependent on many site-specific factors, such as mineralogy, geometry, and microstructure of the rocks, as well as geometrical constraints on the type of groundwater flow, e.g., porous or fracture flow. Studies of natural radionuclide-bearing groundwater systems often fail to discern a measurable effect of alpha-recoil processes on radionuclide transport above the background uncertainty introduced by the spatial heterogeneity of the geological system. Consequently, the effects of the ***Alpha-Recoil*** processes that occur on radionuclide transport are thought to be minor. These effects have therefore been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.7.5.4 FEP Number: W100
FEP Title: ***Enhanced Diffusion***

SCR-6.7.5.4.1 Screening Decision: SO-C

Enhanced Diffusion *is a possible consequence of* ***Chemical Gradients*** *that occur at material boundaries. However, the distances over which* ***Enhanced Diffusion*** *could occur will be small in comparison to the size of the disposal system. Therefore, the effects of* ***Enhanced Diffusion*** *across* ***Chemical Gradients*** *at material boundaries have been eliminated from PAs on the basis of low consequence to the performance of the disposal system.*

SCR-6.7.5.4.2 Summary of New Information

Enhanced *Diffusion* only occurs where there are higher than average chemical gradients. The spatial extent of chemical gradients should be quite limited and as enhanced diffusion occurs, it will tend to reduce the chemical gradient. Thus, the driving force for the enhanced diffusion will be reduced and eventually eliminated as the system approaches steady state or equilibrium conditions. Due to the limited spatial extent of enhanced diffusion, its effect on radionuclide transport should be small.

The effects of ***Enhanced Diffusion*** across ***Chemical Gradients*** at material boundaries have been eliminated from PAs on the basis of low consequence to the performance of the disposal system. Changes have been made to the FEP discussion for clarity and editorial purposes.

SCR-6.7.5.4.3 Screening Argument

Processes that may be induced by ***Chemical Gradients*** at material boundaries include the formation or destabilization of colloids. For example, cementitious materials, emplaced in the WIPP as part of the waste and the seals, contain colloidal-sized phases such as calcium-silicate-hydrate gels, and alkaline pore fluids. ***Chemical Gradients*** will exist between the pore fluids in the cementitious materials and the less alkaline surroundings. Chemical interactions at these interfaces may lead to the generation of colloids of the inorganic, mineral fragment type. Colloidal compositions may include calcium and MgOr, calcium hydroxide, calcium-aluminum silicates, calcium-silicate-hydrate gels, and silica. Concentrations of colloidal suspensions originating from concrete within the repository are considered in PA calculations even though expected to be extremely low.

Distinct interfaces between waters of different salinities and different densities may limit mixing of the water bodies and affect flow and contaminant transport. Such effects have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system.

SCR-6.8 Ecological Features, Events, and Processes

SCR-6.8.1 Plant, Animal, and Soil Uptake

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

Animal Uptake (W102)
Accumulation in Soils (W103)

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

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

SCR-6.8.1.1.2 Summary of New Information

DOE has stated that FEPs related to ***Plant Uptake, Animal Uptake***, and ***Accumulation in Soils*** have been eliminated from the compliance assessment calculations on the basis of low consequence. DOE indicated that the screening of these FEPs is justified based upon the results of PA calculations, which show that releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite beds within the Salado Formation. PAs for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to ***Plant Uptake*** and ***Animal Uptake*** in the accessible environment have been eliminated from PA calculations on regulatory grounds.

SCR-6.8.1.1.3 Screening Argument

The results of the calculations presented in Section 6.5 show that releases to the accessible environment under undisturbed conditions are restricted to lateral releases through the DRZ at repository depth. Thus, for evaluating compliance with the EPA's individual protection requirements in 40 CFR § 191.15, FEPs that relate to ***Plant Uptake***, ***Animal Uptake***, and ***Accumulation in Soils*** have been eliminated from compliance assessment calculations on the basis of low consequence.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to ***plant uptake*** and ***animal uptake*** in the accessible environment have been eliminated from PA calculations on regulatory grounds. ***Accumulation in Soils*** that may occur within the controlled area would reduce releases to the accessible environment and can, therefore, be eliminated from PA calculations on the basis of beneficial consequence.

SCR-6.8.2 Human Uptake

SCR-6.8.2.1 FEP Number(s): W104, W105, W106, W107, and W108
FEP Title(s): ***Ingestion*** (W104)
Inhalation (W105)
Irradiation (W106)

Dermal Sorption (W107)
Injection (W108)

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

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

SCR-6.8.2.1.2 Summary of New Information

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

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

SCR-6.8.2.1.3 Screening Argument

As described in Section 8.1.1, releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite interbeds within the Salado. Because of the bounding approach taken for evaluating compliance with the EPA's individual protection requirements in 40 CFR § 191.15 and the groundwater protection requirements in Subpart C of 40 CFR Part 191 (see Sections 8.1.2.2 and 8.2.3), FEPs that relate to human uptake by ***Ingestion, Inhalation, Irradiation, Dermal Sorption,*** and ***Injection*** have been eliminated from compliance assessment calculations on the basis of low consequence.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to human uptake in the accessible environment have been eliminated from PA calculations on regulatory grounds.

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