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Technical Memorandum

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Subject: WIPP--Examination of Mining and Hydraulic Conductivity

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To: Public Rulemaking Docket A-92-56

Abstract

In light of public comments, we have examined the issue of mining closer and concluded that mining could affect the hydrologic properties of formations overlying the WIPP waste area, with emphasis on the Culebra Dolomite. Examination of the mapped distribution of potash within the Land Withdrawal Area and discussions with Carlsbad area Bureau of Land Management (BLM) staff indicate that there is no minable potash immediately above the planned waste panels. No other minable reserves of similar quality and type to those mined elsewhere in the Delaware Basin are located within the Land Withdrawal Area Boundary. The lack of potash rules out scenarios that would involve direct connections between a potash mine and the waste panels. Using current BLM Potash Reserve Lease Grade criteria as estimated by Griswold (GRI95), SCA estimates that the closest lateral approach of potash (sylvite) to the planned waste panel footprint is approximately 1300 feet; the closest lateral approach of the potash to the waste shaft is approximately 2500 feet. A drilling intrusion with release to the Culebra Dolomite is needed for mining to have a significant effect on radionuclide migration to the accessible environment.

Strain induced fracture aperture increases have been modeled by SCA on a "unit mine" basis (see EPA96). The greatest effects (fracture aperture increases) on the Culebra from mining are expected to occur at a mine boundary. From this modeling, it is predicted that hydraulic conductivity increases of a few orders of magnitude may occur. Important parameters in this analysis are the number of pre-existing fractures and location relative to the mine boundary. The presence of 1) fewer pre-existing fractures and 2) a location within the mine near its boundary result in the highest fracture aperture, and therefore hydraulic conductivity, increases. From a comparison of the position of the potash and the waste panels, it is expected that the area of ground-water flow and transport immediately south of the waste area would not be greatly affected. Most of the effect on hydraulic conductivity would occur in the high transmissivity zone in the Culebra Dolomite southeast of the waste panels. The varying hydraulic conductivity increases could be modeled several ways.

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Introduction

This report presents information on the inclusion of mining in the final 40 CFR 194 rule. The proposed rule (60 Fed. Reg. 5774; January 30, 1995) excluded mining from consideration, but EPA has re-evaluated this position in light of numerous public comments on this issue.
Mining for resources occurs in the vicinity of the Waste Isolation Pilot Plant (WIPP) and could disturb the disposal system. EPA has therefore required that the effects of mining be considered.

Potash resources in the vicinity of the disposal system can be and are extracted by excavation mining. Potash resources also exist within the Land Withdrawal Area. These resources lie primarily in narrow zones of the McNutt Member of the Salado Formation, which mainly consists of impure halite (NaCl) with some thin anhydrite interbeds (GRI82). The McNutt Member is found at shallower depths than the mined portion of the disposal system. No other minable resources, including the halite itself, are considered economically viable in the vicinity of the WIPP site (NBM78). Sulfur deposits are known south of the WIPP site in Culberson County, Texas. Limited mining of sulfur deposits has occurred there in the past (HEN87) in the Castile Formation, which is below the Salado halite.

* no other resource, Sulfur

We examined the effects of mining and concluded that mining could affect the hydrologic properties of formations overlying the WIPP waste area. From our analysis we believe that the effects to be considered in performance assessment may be limited to considering the changes that mining would induce in the hydraulic conductivity of the disposal system. Mining could induce other changes in the disposal system, but we believe that they would have no significant impact. While 40 CFR 194 does not preclude assessing other effects, ~~we believe that~~ these other mining effects can be reasonably represented by changes in the values for the hydraulic conductivity.

* hydraulic effect only

If there is an intrusion into the planned waste storage area (i.e., repository), distal effects of mining could affect transport of radionuclides in the Culebra Dolomite. The Culebra is the most transmissive unit in the disposal system and the unit currently considered as a primary pathway for radionuclide transport to the accessible boundary. The major effect of mining is expected be a reduction in the time it takes for contaminants in the Culebra to reach the accessible boundary.

Estimates of strain induced by mining related subsidence may increase existing fracture apertures and therefore increase hydraulic conductivity; this increase may be less than a factor of two to several orders of magnitude. The increase in hydraulic conductivity depends primarily on location relative to the mining and the number of fractures assumed for the rock unit. Modeling indicates that the greatest change in hydraulic conductivities should be at a mine boundary (EPA96), with smaller effects felt at a distance from the edge of a mine and at the center of the mined out area.

Background

Potash was first produced from the Delaware Basin in 1931 (BAR93). The Known

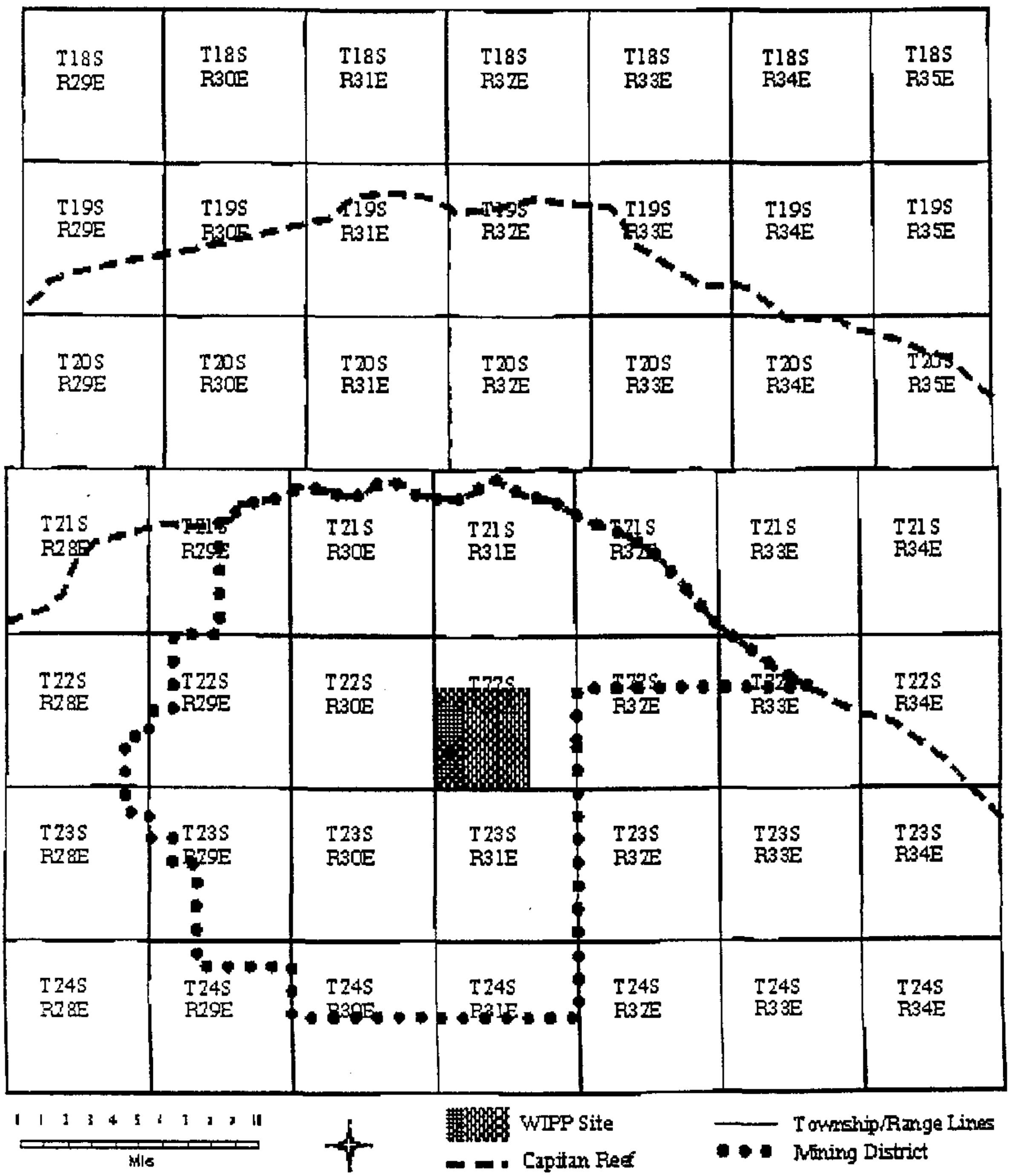

Figure 1 The Known Potash Leasing Area Within the Delaware Basin

Potash Leasing Area (KPLA) covers approximately 400 mi^2 in the Delaware Basin. Figure 1 illustrates

the location of the KPLA that is in the Delaware Basin. About half of this area consists of measured potash reserves as mapped in BLM93. Other areas in the KPLA are barren, contain potash of lower quality than in the area of measured potash reserves, or there is not enough information to distinguish reserve quality. The remainder of the KPLA is located over the Capitan Reef or to the north of the Capitan Reef's outer margin; these areas are not considered part of the Delaware Basin.

The multiple potash ore zones in the McNutt Member are numbered from ore zone 1, which is stratigraphically the lowest. The two ore zones of concern for the Land Withdrawal Area are the 4th and 10th ore zones. While the depth of the two ore zones vary slightly across the LWA as they dip to the southeast, the 4th ore zone is at about 560 meters (1750 feet) above sea level, and the 10th ore zone is at about 625 meters (1950 feet). In the LWA, the 4th ore zone primary target mineral is langbeinite (potassium magnesium sulfate). In the 10th ore zone, the primary target mineral is sylvite (potassium chloride).

Using the present leasing criteria cutoff, the 4th ore zone occurs primarily in the northern part of the LWA and north of the proposed WIPP waste storage area. Figure 2 illustrates the location of the 4th and 10th ore zones relative to the waste panels. The 10th ore zone is more widespread, but it is limited to the eastern, northeastern and southeastern part of the site, except for a concentration directly north of the WIPP waste area. The McNutt Member above the WIPP waste area is considered to be barren with little potash or very thin seams. The closest that potash reserves come to WIPP is over 1000 feet away laterally. The vertical separation between the planned waste area and the 4th ore zone (which is the deepest of the two ore zones) is about 150 meters (450 feet) or more. Since there is no minable potash or other minerals of current interest above the waste panels, there would be no scenarios that connect the waste directly to

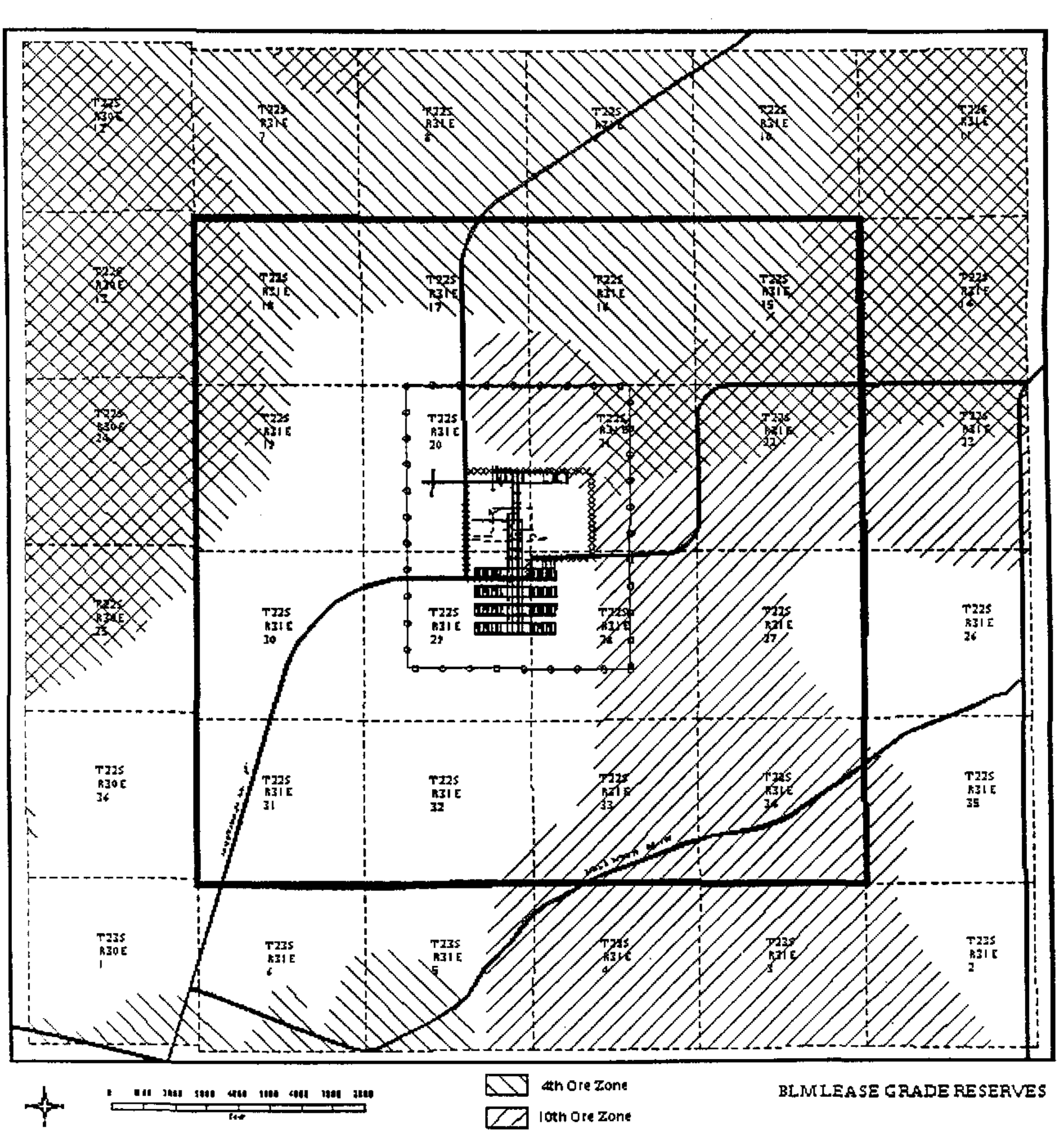

Figure 2 4th and 10th Ore Zones in the Land Withdrawal Area the old brown report

no solution mining

a mined out zone via a drilling intrusion as suggested in SCA94a and SCA94b.

There is no solution mining of potash in the Delaware Basin because solution mining is not currently feasible. The halite which surrounds the sylvite ore is more soluble than the ore itself. According to NMB85, continuous mining of the potash is most common, but blasting is also used. The minimum mining height for the 4th ore zone is 1.9 meters (6 feet) and for the 10th ore zone the minimum mining height is 1.4 meters (4.5 feet). These mining height estimates are based on economics and technology. In many cases the mines will be 1.9 meters (6 feet) even if the seam thickness is less because of the clearance heights required by the mining equipment. These ore zones are both thick enough for mining only in the northeast part of the LWA; elsewhere the thickness of the ore zones is such that only one of the two ore zones is thick enough for mining. Most of the LWA surface subsidence would be a result of mining one zone. The amount of removed material should be in the range of about 1.9 to 3.8 meters (6 to 12 feet), with the most common mine height around 1.9 meters (6 feet) if there is only one zone. Using the surface subsidence relationship quoted in EPA96 (S = sHbe), a subsidence factor of 0.67 (s), cavity height of 1.9 meters (H), an extraction of 90% (b) and assuming no backfill (e=1, the entire cavity is available to be subsided), then surface subsidence would be 1.1 meters (3.6 feet). In the northeast part of the LWA using 3.8 meters (12 feet) to represent two mined ore zones in the equation, 2.3 meters (7.2 feet) of surface subsidence would be expected. Except for the northeast area of the WIPP site, the assumption in EPA96 that 2.7 meters (8.5 feet) would be mined is probably an overestimate of the height of the cavity produced from the mining.

Calculation of mining rate

Since there is mining around the Land Withdrawal Area it is possible that mining could occur in the Land Withdrawal Area once institutional controls are no longer effective. Existing mines in the area have operated for over 60 years and have additional potential operating periods as long as 125 years (EPA96). New mines could extend the use of the resource even further.

125 years of mining.

In order to estimate the possibility of mining in the LWA, we approached the calculation of the rate of mining in a manner philosophically similar to that used for drilling. We looked at the historical record and derived a rate based on the available information. However, it is not possible to use exactly the same process for estimating rates for mining and drilling because of their differences. The area of mined material is important for estimating the rate of mining, whereas borehole size is not important for drilling rate estimates. While the rate of mining is assumed to continue at the same rate as it has in the past--similar to drilling--EPA assumes that the mining of the LWA will occur just once because the mineral deposit will have been depleted. However, exploratory drilling for resource could still continue even if the potash has been mined.

exploration only in future

Since 1931 mining of the different potash ore zones has covered an area (in the Delaware Basin south of T20S) of over 40 mi^2 as estimated from a 1993 map of the potash resources (BLM93). Using 9700 mi^2 as the approximate area of the Delaware Basin, then approximately more than 0.4% of the Delaware Basin has been mined for potash over the past 62 years (1993-1931). (In addition, limited sulfur mining has occurred in Culberson County,

Sulfur

Texas, although not in the same geological formation.) Unlike the available drilling rate information found in databases, data on mining is not as accurate, potentially leading to some estimation errors. For these reasons the 0.4% is thus rounded upward to produce a conservative estimate of the rate of mining of 1% (1 in 100 probability) of the Delaware Basin area for the last 100 years.

human intrusion

Potential mining scenarios

Scenarios at WIPP can be divided into two categories where: 1) the disposal system has no drilling or mining events and 2) the disposal system has either human intrusion via drilling or mining or both. Human intrusion into the waste via drilling is believed to be necessary in order to create a significant pathway to transmissive geologic units or to the surface with or without mining. The planned WIPP waste storage area is overlain by an area barren of minable potash mineralization. The nearest minable potash (the only mineral of current interest within the LWA boundary) is over 1000 feet away laterally, so it is not possible to have a scenario in which there is mining directly above the waste panels. There are, however, indirect effects from mining that may affect radionuclide transport in the event of a drilling intrusion.

There are no scenarios involving drilling intrusions that would result in the direct coupling of waste to a mined area. The scenarios remaining are ones in which nearby mining could affect the transport of radionuclides after they are deposited in the Culebra Dolomite by a drilling intrusion. The remaining detrimental mining-related scenarios might include (EPA96):

- Change in flow directions of water-bearing members if a vertical hydraulic connection is created by subsidence.
- Formation of subsidence-related surface depressions where water could accumulate and alter local recharge characteristics.
- Damage to borehole or shaft seals by subsidence effects.
- Problems created by solution mining.
- Increased hydraulic gradient if significant flow from water-bearing strata into the mine workings occurs.
- Increased hydraulic conductivity of water-bearing formations above the mining horizons due to subsidence.

All of the mining related scenarios except the increased hydraulic conductivity are expected to have no significant impact on the disposal system. ~~The topic of~~ increased hydraulic conductivity is discussed further in this paper. The reader is referred to EPA96 for information on why these other scenarios are not expected to have any significant impact on the disposal system.

Increased hydraulic conductivity due to mining

Hydraulic conductivity in the Culebra is expected to increase as a result of mining. The changes in hydraulic conductivity can be estimated by: 1) identifying the potential strain to which the rock is subjected (see EPA96), 2) calculating the fracture aperture increase, and 3) calculating the hydraulic conductivity using a relationship based on parallel plate theory and the cubic law for fluid flow. Assumptions for this exercise are: 1) all strain goes into increasing the fracture aperture (this is conservative, because some of the strain will probably be absorbed by the rock), 2) 0.071% strain is upper bound on strain (EPA96) and the compressive strain is ignored, 3) initial hydraulic conductivity is 7 m/yr (SCA95), and 4) the number of fractures is 10.

Parameter	Value
aquifer thickness (D)	= 7.7 m
viscosity (μ)	= 0.001 Pa*s
density (ρ)	=1000 Kg/m^3
gravitational constant (g)	=9.79 m/s^2
equivalent hydraulic conductivity ($K\varepsilon$)	=7 m/y = 2.24 x 10^{-7} m/s
tensile strain	= 0.071% = .0007 m/m
total displacement	= 7.7 m x 0.0007 m/m = 5.4 x 10^{-3} m

The equation used for fracture aperture (w) is

$$w=[(K\epsilon 12\mu D)/(\rho g N)]^{1/3}$$

Using the parameter values above, w = 5.9 x 10^{-5} m. Total displacement divided by the number of fractures produces 5.4 x 10^{-4} m displacement per fracture. The displacement per fracture is added to the pre-existing fracture aperture to produce the total aperture:

$$w_{\text{strain}} = 5.9 \times 10^{-5}\ \text{m} + 5.4 \times 10^{-4}\ \text{m} = 6 \times 10^{-4}\ \text{m}$$

The strain-altered effective hydraulic conductivity, K,

$$K = \frac{w^3 \rho g N}{12\ \mu D} \qquad \text{where } w = w_{\text{strain}} = 6 \times 10^{-4}\ \text{m}$$

$$K = \frac{(6 \times 10^{-4})^3 \times 1000 \times 9.79 \times 10}{12 \times 0.001 * 7.7}$$

$$K = 2.3 \times 10^{-4}\ \text{m/s} = 7.2 \times 10^{3}\ \text{m/y}$$

The original hydraulic conductivity was 7 m/yr and the newly calculated hydraulic conductivity for the highest zone of hydraulic conductivity is about 7,000 m/yr. If one fracture had been used the recalculated hydraulic conductivity would have been higher. If more than 10 fractures had been used, the recalculated hydraulic conductivity would have been less. The 1992 performance assessment (SNL92) used a range of 1 to 124 fractures (as calculated from the fracture spacing distribution) for the 7.7 m Culebra thickness. The median number of fractures was 19. Assuming that Sandia's estimate of the fractures is accurate, then the use of 10 fractures for this analysis may overestimate the hydraulic conductivity changes to be expected. In addition, due to the nature of and assumptions used in the strain analysis (e.g., all strain goes into the fractures with none absorbed by the rock), the strain analysis may be a bounding condition as well. The factor of 1000 is therefore expected to be a reasonable upper bound on the hydraulic conductivity increase.

Incorporation of mining into the performance assessment

40 CFR 194.32 requires the inclusion of mining in WIPP performance assessments. §194.32(a) states that "Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame. §194.32(b), "Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame." Once the mining event occurs in the Land Withdrawal area, no more mining is assumed to occur. It can be relatively straightforward to include this into the performance assessment process. This section discusses one general approach that could be used to incorporate mining into the current performance assessment. Other approaches could be used as well.

The key question for the performance assessment is the timing of a mining event. If there is a drilling intrusion event that deposits radionuclides in the Culebra, mining events early in the regulatory time period will impact radionuclide migration rates more than a later mining event. The rule provides the probability, but not the timing. The timing of the mining event can be determined by randomly selecting the timing of a mining event.

The final rule requires performance assessments to assume that, in each century after closure of the repository, there will be a 1 in 100 chance that a single mining event will occur within the controlled area. For each century during the regulatory time frame, performance assessments should determine whether this mining event will occur, based on the 1 in 100 probability, proceeding one century at a time from the start of the 10,000 year period. If a positive determination is made, then performance assessments must assume that the single mining event occurs at the start of that century and further assume that no mining will occur thereafter. Once the century (or individual year) is identified, then the modeling system would have to incorporate the necessary changes to the hydraulic conductivities. This process is discussed below.

Before a mining event occurs, the ground-water model would use a "base-case" set of hydraulic conductivities derived from field measurements. After a mining event the ground-water model would have to use a "mining-case" set of hydraulic conductivities. The mining-case hydraulic conductivity (HC) fields would consist of the base-case set of HC-fields that have been modified by a factor of up to 1000. The amount of change would depend on the location of the data. Some of the hydraulic conductivities away from the mining may not change much, but the hydraulic conductivities at a mine boundary may change the full factor of 1000. Since the hydraulic conductivities change with a mining event, it is necessary to have one set of hydraulic conductivities for the base case and one set for the mining case. So, if there were to be 1000 realizations modeled, then 2000 HC-fields would need to be generated. At the time the mining event is expected to occur, the mining HC-field should then be incorporated.

In order to keep the numerical model from creating numerical instabilities, it is reasonable to allow the effects of mining to be applied gradually (via a linear interpolation scheme). This gradual application of the hydraulic conductivity changes, over a period of time such as 100-200 years of model time, should help to mitigate such instabilities.

The rule states that "assessments may be limited to changes in hydraulic conductivity." The preambles provides instructions that location specific values hydraulic conductivity can be treated as sampled parameters with each location having a range of values varying between unchanged and increased 1000-fold. As discussed earlier in this paper and as calculated from the strain analysis from EPA96, the factor of 1000 in hydraulic conductivity increases would be found around the edge of the mining boundary; elsewhere, the increase would be smaller. The modification of the location specific hydraulic conductivities is therefore spatially dependent. However, the preamble also states "that other numerical changes to the hydraulic conductivity values may be more appropriate for use in representing the effects of mining." An alternative approach could include the following: The barren area hydraulic conductivity increase is less than that in the mined area and the increase is considered as constant throughout the barren area. From the strain analysis in EPA96, it appears that the change in hydraulic conductivities may be within the uncertainty of the hydraulic conductivities; this would depend on the number of fractures assumed. In the mined area, the hydraulic conductivity increase is greater and the increase is sampled from a distribution between about 10 and 1000. This sampled increase could then be applied everywhere across the mined area. Both of the approaches discussed here treat the hydraulic conductivity changes as location specific and both incorporate the 1000-fold increase as discussed in the preamble. There may be additional approaches to those discussed here. Regardless how changes to the hydraulic conductivity are determined, the method will need to be thoroughly discussed and documented in compliance applications.

Summary

40 CFR Part 194 requires consideration of mining-related scenarios in assessing the performance of WIPP. Since there is little to no potash or other minerals of current interest directly above the waste panels, it appears that there will not be a direct connection between a drilling intrusion into the waste panels and a potash mine. Other effects of mining could occur but they are not expected to have a significant detrimental impact on the repository or radionuclide migration (EPA96). We believe that the only significant effect of mining is to increase hydraulic conductivity of units in the disposal system. Depending on the number of pre-existing fractures and location relative to a mine boundary, an increase of up to 1000-fold is a reasonable estimated upper bound for the change in hydraulic conductivity of the Culebra

Dolomite. A 1% rate of mining per 100 years, estimated from historical information in the Delaware Basin, is a reasonable conservative estimate that can be used to randomly select a time at which mining could occur in the future. Once the times of mining are identified, there are multiple ways that increased hydraulic conductivities can be incorporated into performance assessments.

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