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IDENTIFICATION OF ISSUES RELEVANT TO THE FIRST RECERTIFICATION OF WIPP

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New Mexico

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment of New Mexico. The WIPP Project, located in southeastern New Mexico, became operational in March 1999 for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned the EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-AC04-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, and the National Defense Authorization Act for Fiscal Year 2000, Public Law 106-65, continued the authorization.

The EEG performs independent technical analyses on a variety of issues. Now that the WIPP is operational, these issues include facility modifications and waste characterization for future receipt and emplacement of remote-handled waste, generator site audits, contact-handled waste characterization issues, the suitability and safety of transportation systems, mining of new panels, and analysis of new information as part of the five year recertification cycles as mandated by the WIPP Land Withdrawal Act. Review and comment is provided on the annual Safety Analysis Report and Proposed Modifications to the Hazardous Waste Facility Permit. The EEG also conducts an independent radiation surveillance program which includes a radiochemical laboratory.

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ACRONYMS

CBFO	Carlsbad Field Office
CCA	Compliance Certification Application
CRA	Compliance Recertification Application
CH TRU	Contact Handled Transuranic waste
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
LANL	Los Alamos National Laboratory
LWA	Land Withdrawal Act
PA	Performance Assessment
STTP	Source-Term Waste Test Program
TRU	Transuranic
UIC	Underground Injection Control
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

One goal of the WIPP Land Withdrawal Act was to assure the safe disposal of the nation's defense transuranic waste into a deep repository in southeast New Mexico. The governing legislation required the U.S. Department of Energy (DOE) to provide to the U.S. Environmental Protection Agency (EPA) analyses of the anticipated performance of the repository. Disposal operations could not begin until the EPA determined that the project demonstrated compliance with EPA Standards (40 CFR 191) and EPA Criteria (40 CFR 194) for such disposal. The Land Withdrawal Act inherently recognized that the EPA Certification would have to rely on best available knowledge at the time when the application was submitted. The Act also recognized that after the initial certification of WIPP and start of disposal operations, operating experience and ongoing research would result in new technical and scientific information. Thus, the legislation requires recertification of the WIPP every five years, following the first receipt of waste. This report updates issues that the Environmental Evaluation Group (EEG) considers important as the Department of Energy (DOE) works towards the first recertification. These issues encompass a variety of technical areas including actinide solubility, fluid injection scenarios, solution mining, Culebra flow and transport, spallings modeling, and non-random waste emplacement.

Given the 24,000-year half life of ^{239}Pu, understanding the characteristics of plutonium in the WIPP environment is obviously important to the validity of long-term performance assessment of the repository. Some uncertainty remains in the understanding of the persistence of higher oxidation states because of reliance on modeling (with its associated assumptions) and limited experimental results. The EEG recommends additional experimental work towards parameters for a proposed conceptual kinetic model of plutonium solubility. In addition, the EEG recommends an intrusion scenario during performance assessment which would account for a heterogeneous, non-inundated repository which may include persisting higher oxidation states of plutonium.

Intrusion scenarios including the consequences of fluid injection were rejected at the time of the Compliance Certification Application (CCA). With increasing drilling activity in the vicinity of the WIPP (Figure 1), fluid injection scenarios should be re-examined for recertification performance assessment. These scenarios should consider potential consequences from oil field secondary recovery techniques such as waterflooding in addition to ancillary injection operations such as brine disposal and pressure maintenance wells. The WIPP resides in a resource rich locale and performance assessment should consider all reasonable activities associated with such a location.

Likewise, solution mining scenarios should also be reconsidered during recertification. Solution mining should be anticipated for extraction of potash reserves as well as for the excavation of salt caverns for storage of natural gas, oil field wastes, and chemical feedstocks. Consideration of solution mining for potash extraction is a natural alternative for a maturing mineral district as ore-grades decrease below the economic cutoff necessary for traditional mining methods. Dissolution of halite for creation of underground storage caverns is a practice already used in the Delaware Basin for oil field waste and natural gas. Research suggests that it may also be a viable method for storage of other items such as chemical feedstocks.

The Culebra dolomite unit of the Rustler Formation is acknowledged as a likely pathway for breach of the WIPP repository. Hence, long-term performance assessment requires an accurate understanding and modeling of flow and potential actinide transport.

Most of the issues concerning the Culebra that were raised at the time of the CCA resulted from poor discretization of the modeling grid and the inherent heterogeneity of the aquifer. The DOE had originally planned to replace the previous flow code with MODFLOW and implement a finer grid. This coupled with a new transport code, STAMMT-L, would have addressed problems with numerical dispersion and spatial truncation errors. In addition, STAMMT-L incorporates a dual-porosity, multi-rate approach, which the DOE demonstrated to be a superior representation of transport within the heterogeneous character of the Culebra. The DOE had originally planned to address issues concerning the Culebra, but now plans no changes to the conceptual model during recertification.

The EEG remains concerned over the continuing water level increases in the Culebra aquifer. The DOE is currently engaged in an effort to determine the source, or sources, of the rising water elevations, which have continued to increase for the last 14 years. Until a cause is determined, the validity of the Culebra conceptual model used for performance assessment is in question.

The EEG recommends that the DOE reconsider its decision **not** to change the Culebra modeling codes and grid discretization. In addition, the EEG urges the DOE to conclusively determine the source of the water level increases and adjust the conceptual model accordingly.

Spallings consist of repository waste material that fails due to a rapid reduction of pressure caused by penetration of the repository by a drill hole. The failed material would be transported up the drill hole to the surface by gas flow. The CCA performance assessment demonstrated the importance of spallings as a potential release mechanism. The spallings model used during the CCA did not adequately characterize the physical processes of spall. Work was in progress by the DOE on a new spallings model that was intended for use during recertification. This model was to improve predictions of long-term performance, reduce uncertainty, and enhance public confidence. However, the DOE has recently announced that the new model would only be used for impact analysis and not for recertification performance assessment. The EEG urges the DOE to reconsider and to use the new model for performance assessment.

Random emplacement of waste in the repository was assumed during the CCA performance assessment. However, waste emplacement practice since the 1999 opening has demonstrated that random emplacement is not likely. Specific waste streams shipments to WIPP depend on the DOE's agreements with the host states, and, on the readiness of particular waste streams for shipment. It has been previously demonstrated by the DOE that non-random emplacement could increase the mean release values. The EEG recommends that DOE develop a waste loading plan based on their shipment schedule. All intrusion scenarios could then consider non-random emplacement, providing better estimates of releases.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Project, located in Southeastern New Mexico was constructed by the U.S. Department of Energy (DOE) to provide permanent disposal of long-lived transuranic (TRU) waste from the U.S. defense activities and programs. The WIPP Land Withdrawal Act (LWA) requires that the facility must comply with 40 CFR 191, Subpart A during the period when radioactive waste is being emplaced and with 40 CFR 191, Subpart B and 40 CFR 194 for long-term disposal. Moreover, the U.S. Environmental Protection Agency (EPA) was assigned the responsibility to make that determination. In May 1998, the EPA certified that the WIPP met the requirements of 40 CFR 191 and 194.

The LWA inherently recognizes that the disposal facility represents a pioneering effort. Undoubtedly, as more scientific and technical information becomes available, there will be a need to revisit the certification decision. Hence, the enabling legislation requires recertification of the WIPP every five years after the first receipt of waste. The repository began receiving CH TRU wastes in March 1999. The first recertification by the EPA is required by March 2004, the second recertification by March 2009, etc. until the closure of the repository shafts.

The EPA standards specify the maximum allowable amount of radioactive material that can escape from the repository to the accessible environment for the regulatory period of 10,000 years. Because this is such a long time, the cumulative releases were predicted with performance assessment calculations. Specifically, the calculations attempt to represent the amount of material released as the result of some future drilling effort inadvertently penetrating the long forgotten repository. By definition, the performance assessment: (1) identifies the features, events and processes that might affect the disposal system, (2) examines their impact on the behavior of the disposal system, and (3) considering associated uncertainties, estimates the cumulative releases of radionuclides.

Experience has shown that the performance assessment must be viewed as an iterative process. As such, the contributions of various factors can achieve greater or lesser significance, depending on the performance assessment models. For example, three performance assessments were published in 1990 (Bertram-Howery et al. 1990), 1991 (SNL 1991), and 1992 (SNL 1992). During that time frame, the calculated releases were most sensitive to the drilling rate, actinide solubility, and actinide retardation (Helton et al. 1992). After a performance assessment publication hiatus of three years and a redesign of the conceptual models, the calculated releases from the 1996 performance assessment (DOE 1996) were reported to be most sensitive to three drilling phenomena - spalling, cavings, and cuttings.

In the ensuing time period since the Certification Decision (EPA 1998), the Environmental Evaluation Group (EEG) has identified unresolved Performance Assessment (PA) issues pertinent to the Compliance Recertification Application (CRA), (Chaturvedi et al. 1999; Silva et al. 1999 (Appendix A); Rucker et al. 2000; Silva 2000). This report updates the EEG's views on the following issues: (1) actinide solubility, (2) fluid injection, (3) solution mining, (4) Culebra transport, (5) spallings, and (6) non-random waste emplacement.

In November 2001, the DOE issued the Recertification Project Plan (DOE 2001a) outlining the intended activities and timeline for completion of the CRA. Since the Recertification Project Plan was issued, three CBFO/EPA Working Meetings (DOE 2001b; 2002a; 2002b) have been conducted for presentation of information and studies pertaining to the recertification.

The EEG considered that an update of these unresolved issues would be important and timely as the DOE is focusing efforts toward compilation of the CRA. The DOE had originally planned to address several of these issues as part of the recertification, but have since modified their plans. It is recognized that the Recertification Project Plan reflects a snapshot in time, and that the DOE's schedules and activities may change because of unforeseen events or as the result of ongoing investigations. Therefore, this report reflects the EEG's understanding of the DOE's intent at the time of writing.

2.0 UPDATE ON UNRESOLVED ISSUES

Since the EPA Certification Decision in 1998, the EEG has commented on issues which they considered to be unresolved following the Compliance Certification Application (CCA) (DOE

1996). In light of several ongoing investigations by the DOE, as well as the DOE's stated objectives in the Recertification Project Plan, the EEG decided to update the previously identified issues for possible consideration in the 2004 CRA.

2.1 Actinide Solubility

Plutonium (Pu), specifically ^{239}Pu, is the major actinide of concern for long-term repository performance. With a 24,000-year half-life, ^{239}Pu will retain approximately 75 percent of its radioactivity over the 10,000-year regulatory period. Therefore, it is important to know the characteristics of Pu in the WIPP environment, particularly given that previous iterations of performance assessment were found be sensitive to actinide solubility (Helton et al., 1992). These characteristics include: (1) potential oxidation states, (2) solubility in the WIPP brines, and (3) its ability to complex with other waste constituents, such as chelating agents, to form more soluble or less sorptive species. Americium-241 (^{241}Am) with a 432 year half-life, is significant to performance assessment during the first 1500 to 2000 years but its solubility is more predictable. Other actinides, with shorter half-lives, will decay substantially during the regulatory period.

2.1.1 Potential Oxidation States

Understanding the potential oxidation states for plutonium is important for performance assessment. The higher states, Pu (V) and Pu (VI), are more soluble in brine than the lower states. This would increase the amount of radioactivity which would be brought to the surface during a human intrusion event. For the CCA, the DOE assumed that Pu would exist only in oxidation states III and IV. The DOE argued that the reduction potential of iron in the waste and waste containers would keep Pu from persisting in the higher oxidation states of V and VI for any substantial length of time. However, Pu (V) and Pu (VI) have been observed in a number of experiments conducted in brines (Villarreal 2002).

Unfortunately Pu chemistry studies with solutions at near-neutral pH are limited. Most Pu studies were conducted for the separation procedures necessary for defense purposes and done under low pH conditions. Hence, there is little literature pertaining to Pu under the WIPP environmental conditions. Also, complicating its study, Pu is capable of existing in a number of valence states. It may have one valence state in the solution phase and a different valence state in the solid phase in contact with the solution (Haschke and Oversby 2002).

To understand the behavior of Pu under the WIPP disposal conditions, the similarities between the chemistry of uranium (U) and Pu were used together with data from several high level waste disposal programs to construct a conceptual model (Oversby 2000). This model starts with the work of Haschke et al. (2000) which showed evidence for the formation of PuO_{2+x} from PuO_2 and moisture. Experimental data show that the value of x in PuO_{2+x} is as high as 0.27. The model, summarized by Haschke and Oversby, describes the reaction scheme for steady-state solution concentrations of Pu and demonstrates the presence of Pu(V) and Pu(VI) in solution:

1. Pu(V) accumulates in PuO_{2+x} as x is increased by spontaneous reaction of PuO_2 with H_2O.
2. The rate of PuO_2^+ dissolution increases with increasing value of x in PuO_{2+x} until it equals the rate of Pu(V) formation and a steady state is established.
3. PuO_2^+ accumulates until its rate of disproportionation into PuO_2^{2+} (i.e. Pu(VI)) and Pu^{4+} equals its rate of entry into solution and a steady state is established.
4. PuO_2^{2+} accumulates until disproportionation and reduction reform PuO_2^{2+} at a rate equal to half the PuO_2^+ dissolution rate and a steady state is established.
5. Pu^{4+} accumulates until its concentration satisfies the K_{sp} for $Pu(OH)_4$ precipitation and the equilibrium of Pu(IV) concentration is established.
6. Metastable $Pu(OH)_4$ spontaneously transforms into PuO_2 and subsequently back to PuO_{2+x}.

A quantitative model could be developed from this conceptual model. Rate constant data would need to be available for steps 1, 3, and 4, and equilibrium thermodynamic data for step 5.

2.1.2 Solubility in WIPP Brines

To characterize the solubility of plutonium in brine, the DOE used an oxidation state analogy. The oxidation state analogy assumes that species of similar oxidation states behave in a similar manner. For example, rather than determining its solubility experimentally, the DOE estimated Pitzer parameters for Pu (IV) from data reported for thorium (Th) (IV). The DOE then argued that the Pu (IV) estimates were conservative because Th (IV) solubility would be consistently higher than Pu (IV) solubility (Triay 2001). However, experiments conducted at the Los Alamos National Laboratory (LANL) (Villareal 2002) with containers of transuranic waste measured higher dissolved concentrations of Pu rather than Th. This strongly suggests "that Th solubility is unlikely to be a realistic or conservative analog for Pu or U under WIPP disposal conditions" (Oversby 2000).

In response to the Oversby (2000) report, the DOE (Triay 2001) reiterated their position for use of the oxidation state analogy and continued, "The key to oxidation state analogy then lies in understanding the chemical conditions where it is and is not applicable, and also understanding the appropriate use, including limitations, as applied to a real problem." The EEG agrees with this statement as it goes to the very point of the EEG's argument, i.e., the analog method cannot account for the ability of Pu to assume higher oxidation states. The total solubility of Pu in solution cannot be predicted by the oxidation state analogy because the lability of Pu between different oxidation states cannot be treated by analogy.

The above mentioned experiments conducted by LANL were termed "The Actinide Source-Term Waste Test Program" (STTP) which attempted to determine actinide behavior in WIPP-like brines. A portion of this study was devoted to the analysis of waste similar to that which resulted from the pyrochemical processing of weapons-grade Pu conducted at Rocky Flats. The residues from this processing are mostly solidified chloride salts used as molten solvents in several extraction processes, i.e. direct oxide reduction (PuO_2 to metal), molten salt extraction (Am from Pu), and molten salt electrorefining (Villarreal 2002).

The STTP was designed to approach the WIPP repository conditions for actinide transport and assumes total brine immersion of wastes (Villarreal 2002). In one publication, the EEG (Haschke and Oversby 2002) has concentrated on the results from the general pyrochemical salt liter-scale tests, i.e. pyrochemical salt tests without additional components such as CO_2, bentonite, etc. These tests were designated L-25, L-26, and L-27. Results from these experiments showed that solution concentrations of Pu rose gradually in L-26 and more rapidly for L-27. The peak concentration for L-27 was about three times higher than for L-26, although they reported similar loading amounts. Pu then decreased and approached an apparent steady-state condition with concentrations of about 4 ppm for L-26 and between 25 to 30 ppm for L-27. Meanwhile L-25 with a much lower initial loading, peaked at 0.17 ppm and decreased to 0.06 ppm. L-27 contained Castile brine while L-25 and L-26 contained Brine A, a simulated Salado brine. These results suggest that the amount of Pu in the system influences the steady-state concentration of Pu and that a mechanism other than thermodynamic equilibrium solubility controls the concentration.

Also, according to the DOE, L-26 showed Pu (VI) which persisted for 1.5 years while L-27's high Pu concentration was identified with Pu (V). The iron mesh did not seem to maintain a reducing environment in these tests (Triay 2001).

The DOE maintains that: (1) pyrochemical salts constitute a small fraction of the waste, and (2) that oxidized Pu would only be produced in microenvironments and would not persist in large quantities in the repository. However, actual persistence and what constitutes "significant quantities" is unknown. Oversby (2001) argues:

> "Discussion of persistence of oxidation states is only appropriate for steady-state conditions. Long-lived transients are likely to be important in at least some human intrusion scenarios. Concentrations of Pu exceeding those predicted in the CCA persisted in the STTP tests for periods of up to 5 years. These high Pu concentrations were probably caused by the presence of Pu (V) and/or Pu (VI)."

The conceptual model presented in Section 2.1.1 has been applied in explaining these STTP results (Haschke and Oversby 2002). Kinetic equations for the model were obtained from analysis of published data. This model predicts the presence of Pu as Pu(V) and Pu(VI). Observed steady-state Pu concentrations in excess of the model predictions are explained by the presence of high Cl^- concentrations and Fe, which promote reduction of Pu(V) and complexation of the Pu(III) product. These results suggest that equilibrium modeling does not adequately predict dissolution behavior of Pu. Kinetic factors should be considered.

2.1.3 Use of FMT For Solubility Modeling

The FMT solubility model was developed for use at WIPP and has not gained widespread acceptance elsewhere. The EEG discovered that the model predicted large differences in actinide sulfate solubilities for different brines that could not be explained on the basis of chemistry. This raised questions concerning the validity of the code. The EEG also disagreed with the EPA's methodology for verification of the code as it was not subjected to comparisons with more widely used codes, nor did it demonstrate the ability of the first model to reproduce results consistent with relevant published data.

The DOE was considering the use of a more widely used code, EQ3/6, for recertification (Knowles et al. 1999; Knowles in DOE 2001b). However, the DOE has apparently reconsidered its decision and is planning on the use of FMT (Patterson 2002).

2.1.4 Complexation With Waste Constituents

The ability of plutonium to complex with other waste constituents involves the effects of organic ligands on the solubility and the partitioning coefficient of plutonium and other major actinides in WIPP brines. Some organic ligands that are known to be in significant quantity in the WIPP waste will act as chelating agents, binding to the actinide, which will keep the actinide from binding with the solid material. This binding will increase solubility by allowing less plutonium to be attached to solid matter in the waste. It will also decrease the partitioning coefficient, a measure of how contaminants are sorbed onto a host rock once it reaches a viable aquifer. However, the potential effects of organic ligands were not included as part of the CCA performance assessment calculations.

The experimental results from the STTP tests showed that the presence of organic ligands (acetamide, acetate, citrate, oxalate, and thiocyanate) elevates Pu solubilities by a factor of 1000 (Oversby 2000). The DOE assumed a well-mixed, homogenous repository and average concentration of the ligands to calculate the affinity of the ligands binding with plutonium. In reality, the repository will not likely be mixed, creating an extremely heterogeneous environment of actinide reactants with ligands. In addition, the DOE argued that the organic ligand, EDTA, would form the strongest complexation with actinides in the IV oxidation state (or An (IV), and that other divalent cations, such as Fe (II) and Ni (II) would use up most of the EDTA, so there would be less to react with An (IV)). On this basis, the impact of citrate was eliminated from further consideration. However, the 140 metric tons of citrate in the waste will form strong complexation species with An (IV) with little competitive reaction from other divalent cations. Therefore, citrate will be bound to a significant portion of Pu (IV) or U (IV) in the WIPP waste (Oversby 2000).

2.1.5 Recommendations

The EEG recommends that, for performance assessment, the DOE consider the effects of increased Pu solubility resulting from complexation with organic ligands. This is especially significant in scenarios which reflect non-random waste emplacement (Section 2.6), in which the repository environment is a heterogeneous mixture of actinides and organic ligands.

The EEG recommends that the DOE explore the development of a conceptual kinetic model of Pu solubility. Additional experimental work is suggested (Oversby 2002) which would allow the application of this model. Necessary parameters are:

(1) The rate of Pu(V) production in $Pu(OH)_4$ as a function of [NaCl] and pH,
(2) The rate of disappearance of Pu(V) from solution as a function of [NaCl] and pH, and
(3) The rate of disappearance of Pu(VI) from solution as a function of [NaCl] and pH.

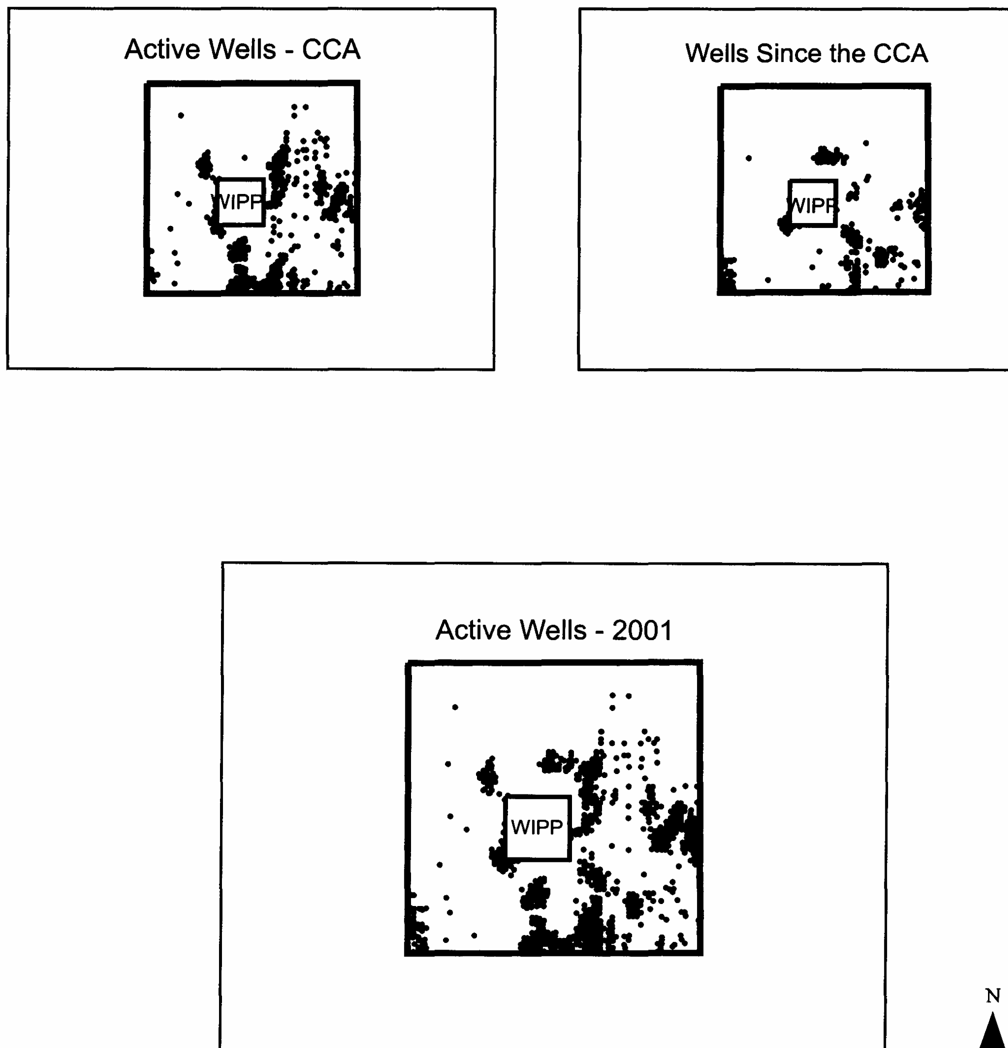
Determination of these parameters can be limited to a range covering the WIPP conditions. Data for (2) and (3) already exist at pH 7.1 and [NaCl] = 2.4 M. Oversby goes on to provide specific recommendations:

> "If data were produced for [NaCl] = 0.1 and 4.8 M at pH 7.1, the chloride dependence of these reactions rates could be evaluated. If the dependence of rates on [NaCl] is not too great, the pH dependence of the rates could be evaluated at a single [NaCl], for example 2.4 M. Tests at pH 9 and 11, together with the existing data at pH 7.1 would give the pH dependence of the rates. The effect of Fe could be evaluated initially by using a single pH and [NaCl] together with two experimental conditions – one with an initial concentration of Fe(II) without a replenishment source and one with an actively corroding piece of Fe metal to provide a constant source of Fe(II) ions. A similar experimental matrix for the oxidation of $Pu(OH)_4$ as a function of [NaCl] and pH would complete the reaction rate data needs. If any of the reaction rates turned out to be a sensitive function of one of the experimental parameters, more detailed studies could be planned."

The EEG urges the DOE to reconsider its decision to use FMT for recertification. The DOE has apparently invested considerable effort in the application of EQ3/6 to the WIPP data and demonstration of its use should enhance public confidence in solubility modeling.

2.2 Fluid Injection

The issues regarding fluid injection have been previously discussed in detail by the EEG (Neill et al. 1998). The 1996 performance assessment calculations did not include scenarios of fluid injection for enhanced oil recovery, a current practice throughout the Delaware Basin (Silva 1996). The DOE rejected its inclusion on the basis that the EPA regulations did not require it. The regulation states: "With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole (EPA 1996)." Also, any affects from fluid injection wells adjacent to the WIPP were not included on the basis of a low probability argument. Figure 1 shows the increase in oil and gas related drilling activity since the time of the CCA.



Includes oil, gas, pressure maintanance, and salt water disposal wells

Figure 1
Comparison of Active Wells - CCA to 2001
Nine-Township Boundary

2.2.1 Waterflooding

In the EEG's opinion this issue is worthy of re-examination during recertification based on the continuing practice of waterflooding for oil recovery enhancement. As of 2001 there were three major waterflooding projects in the New Mexico portion of the Delaware Basin (DOE 2001c).

Waterflooding is a secondary recovery technique used to enhance crude oil recovery by restoring reservoir energy lost during primary production (Willhite 1986). During waterflooding, pressurized water is injected through the well bore into the reservoir. This forces oil, that may be unrecoverable by primary methods, to flow toward the producing well. Waterflooding and other secondary and tertiary recovery methods are encouraged by the State of New Mexico through severance tax relief, promoting maximum extraction of resources.

However, waterflooding has historically presented problems for some oil-bearing zones underlying the Salado Formation. It has been documented in various instances that water has escaped from the collection zone and migrated through the Salado Formation to adjacent properties (Ramey 1976). Probably the most notorious waterflood incident resulted in the Hartman vs. Texaco lawsuit (Complaint CIV93 1349M) filed in the Federal Court for the District of New Mexico. Mr. Hartman claimed that the Texaco Rhodes Yates waterflood project allowed large quantities of injected water to escape out of the approved zone, part and dissolve the Salado Formation, and migrate to Hartman's Bates Lease (Hartman 1993). This lawsuit resulted in compensation to Mr. Hartman.

The EPA concluded that a probability of such a waterflood event occurring in the Salado Formation in the vicinity of the WIPP is extremely low (EPA 1998c). They relied on geological comparisons based on geological descriptions of the Hartman vs. Texaco location provided in a summary of the case and on the DOE characterization, and hence conceptual model, of the Salado Formation at the WIPP. Also, the EPA suggested that the relatively young age of the wells in the vicinity of the WIPP provide some measure of assurance because of better construction and operational practices than those involved in the Hartman case. However, it should be noted that a hypothesized cause of the Culebra water level increase is a leaky injection well in the vicinity of the WIPP (Beauheim 2002).

2.2.2 Brine Disposal

The most common type of injection well in the Delaware Basin is for the disposal of brine water resultant to production of oil and gas. Salt water disposal wells are necessary as a result of an EPA ruling that formation water may no longer be disposed of on the surface.

There are currently 33 salt water disposal wells in the nine-township area surrounding the WIPP site (DOE 2001c). This number is up considerably over the 10 salt water disposal wells in the same area as reported from 1993 (Broadhead et al.1995).

The DOE relies on a low consequence argument and the administration of the Underground Injection Control (UIC) regulations (OCD 2002) as a safeguard against possible consequences from fluid injection. The determination of low consequence is again based upon DOE's modeling and hence conceptualization of Salado Formation (Stoelzel et al. 1996; Stoelzel and Swift 1997). Indeed, alternate modeling suggested that the DOE's modeling may be unrealistic and non-conservative (Bredeheoft 1997a; 1997b).

As for the UIC regulations, despite the required testing and verification by the New Mexico Oil Conservation Division, strong circumstantial evidence suggested a connection between a salt water disposal well and Culebra monitoring well H-9 (LaVenue 1991; Beauheim 1995). The reliance on this program as a safeguard may be in question if injection wells are found to be, in part, responsible for the current Culebra water level increases.

The EPA used a low probability argument to justify the exclusion of fluid injection scenarios. However, the EPA analysis resulted in three different probability values which spanned four orders of magnitude (Silva et al. 1999). This highlights the uncertainty in assigning probabilities for the series of individual events for calculation of the total probability of a leaking well impacting the repository.

The fact that fluid injection scenarios were not included in the CCA performance assessment does not preclude their inclusion during recertification. Recertification can incorporate a re-evaluation of previous information as well as new information. Given the increase in development of wells in the vicinity of the WIPP, there is an increased expectation that extraction from known oil reserves will be optimized by secondary and tertiary recovery techniques.

The OECD/NEA-IAEA Joint International Review Group, in a Peer Review commissioned by the DOE, expressed reservations about rejecting a scenario solely on the basis of regulatory considerations:

> "It would improve the confidence of the reader if the DOE presented the logical or physical arguments for not considering these processes in the assessment, in addition to noting that they are not required in a compliance demonstration. Otherwise, there is an impression that processes that might deserve consideration from a safety perspective have been eliminated" (NEA/IAEA 1997).

The EEG believes that the increasing number of brine disposal wells, along with economic incentives for the use of secondary recovery techniques, reflects on the necessity of screening in fluid injection scenarios into recertification performance assessment calculations. In addition, the DOE should realistically assess potential flow paths in the Salado based on documentation of other fluid injection events. Also, unexplained water level increases in the Culebra aquifer, which raises questions concerning the Underground Injection Control program, undermines the reliance that the DOE puts on the program as a safeguard measure.

2.3 Solution Mining

Consideration of solution mining was not included in the CCA on the basis that it was not occurring in the Delaware Basin in 1996. However, underground storage caverns already exist and interest is growing in solution mining of potash for extraction of minerals. An expansion of the role of salt caverns for storage of natural gas, oil field wastes, and chemical feedstocks is expected (Veil et al. 1996; Bauer et al. 1998; Veil et al. 1998).

Consideration of solution mining for extraction of minerals is the natural progression of alternatives in the life of a mine. Companies which mine various commodities, including potash, consider solution mining following the extraction of higher grade ores through more predictable traditional methods. In addition, ores which were once considered as too low grade become economical with the refinement of new technologies. With this in mind, it is reasonable to assume that solution mining will be considered in the vicinity of the WIPP project for extraction of minerals (NMBMMR 1995). This is especially true since the U.S. Bureau of Land Management has delayed development of oil and gas reserves surrounding the WIPP in favor of prioritizing the extraction of potash. The prioritization policy will push forward in time a decision by potash companies concerning final development of potash reserves. Figure 2 shows the potash reserves and resources in the vicinity of the WIPP.

Another emerging technology is the use of solution mining for dissolution of underground caverns for storage purposes. The DOE has funded considerable research in this area, especially for disposal of oil field waste (Veil et al.1996; Tomasko et al. 1997; Veil et al. 1998). Sites for the underground disposal of oil field waste are typically caverns created by the solution mining of halite for use as brine during oil field drilling, a practice already occurring in the Delaware Basin (Neill et al. 1998).

Solution mining, whether for extraction of resources or for excavation of underground storage, should be considered. Plausible scenarios related to this activity should be evaluated and screened for each recertification as technology in this area continues to be refined.

2.4 Culebra Flow and Transport

The Culebra dolomite unit of the Rustler Formation is acknowledged as a likely pathway for breach of the WIPP repository. This observation underscores the need for an accurate understanding and modeling of Culebra flow and transport by the DOE.

Figure 2
Potash Resources In the Vicinity of WIPP

The National Academy of Sciences WIPP Committee (NAS/NRC 1996) and the EEG (Neill et al. 1998) raised issues regarding the conceptual and numerical model of transport through the Culebra. The DOE had planned to address some of these issues during the first CRA (DOE 2001b), but now plans no changes to the conceptual model (Patterson 2002).

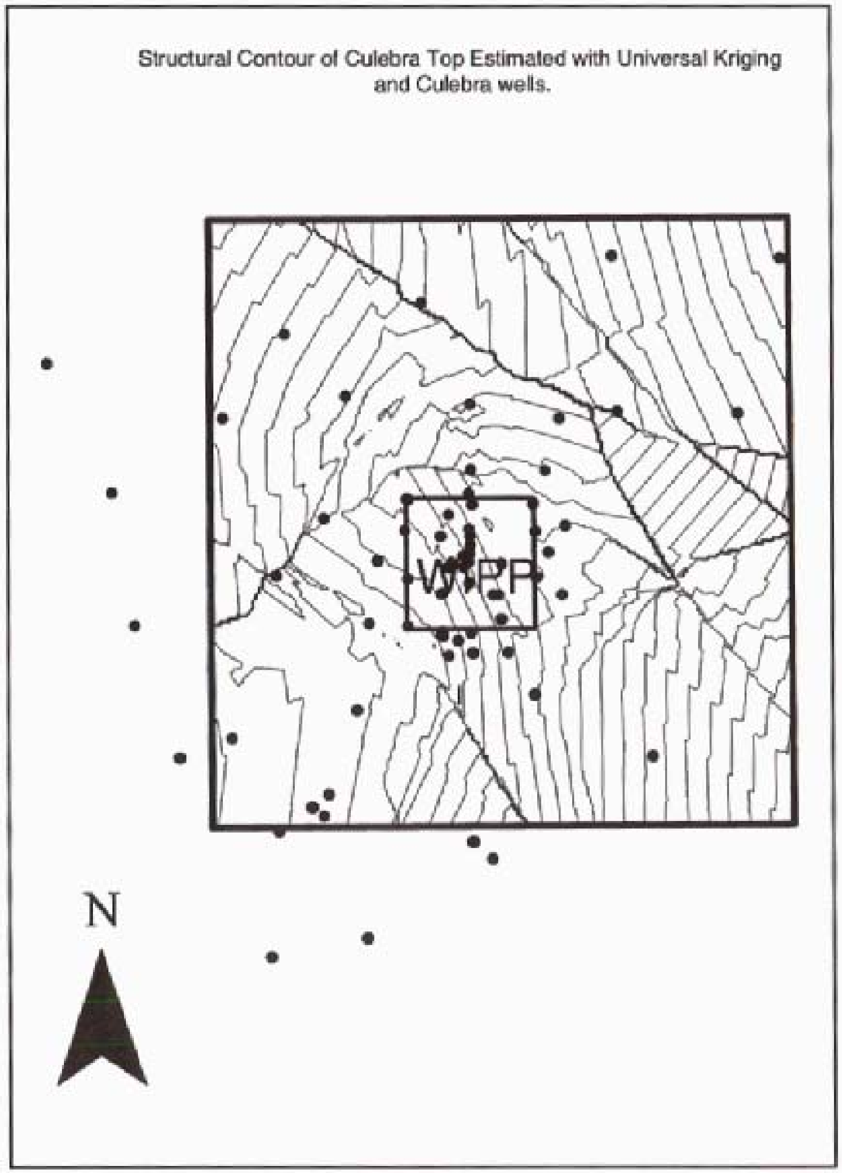
In addition to the issues concerning transport, continuing increases in water level elevations in the Culebra and other formations, raises uncertainty in the flow model. As the transport model follows from the flow model, this also increases uncertainty in the transport model. Figure 3 illustrates the generalized dip of the Culebra and monitoring wells in the vicinity of the WIPP.

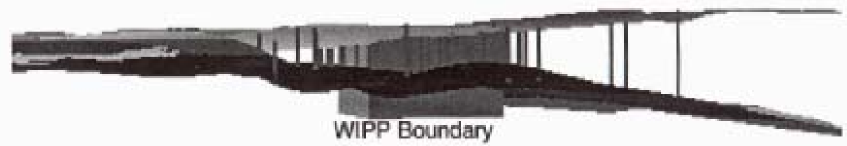
2.4.1 Water Level Increases

The water level in the Culebra began increasing in April, 1988 (Beauheim 1990; Silva 1996) and continues to rise through the date of this report. These increases are also observed in the Magenta unit of the Rustler Formation as well as in some of the more shallow formations (Beauheim 2002).

These increases are of concern in the recertification because 21 of 28 monitoring wells now show water elevations in the Culebra aquifer outside the ranges used for calibration of the CCA transmissivity fields. This may cast doubt on the validity of the steady-state flow model used in the CCA. Also, the reliability of the transmissivity estimates were determined using inverse methods that assumed the Culebra was a non-leaky, two-dimensional aquifer. Increasing water elevations suggest a likely connection of the Culebra with other water-bearing units, raising questions concerning the validity of this assumption as well.

During January 2002, the DOE convened a workshop to address the issues of the water level rises. The stated purpose of this workshop was “to demonstrate an understanding of the WIPP hydrologic system by developing scenarios that account for the observed changes and show that the CCA modeling results remain valid for recertification” (Beauheim 2002). Figure 4 shows the difference in water elevations between the time of the CCA and 2001.





Cross section looking north showing dip of Culebra to the east

Figure 3
Culebra Top with Wells and WIPP Boundary

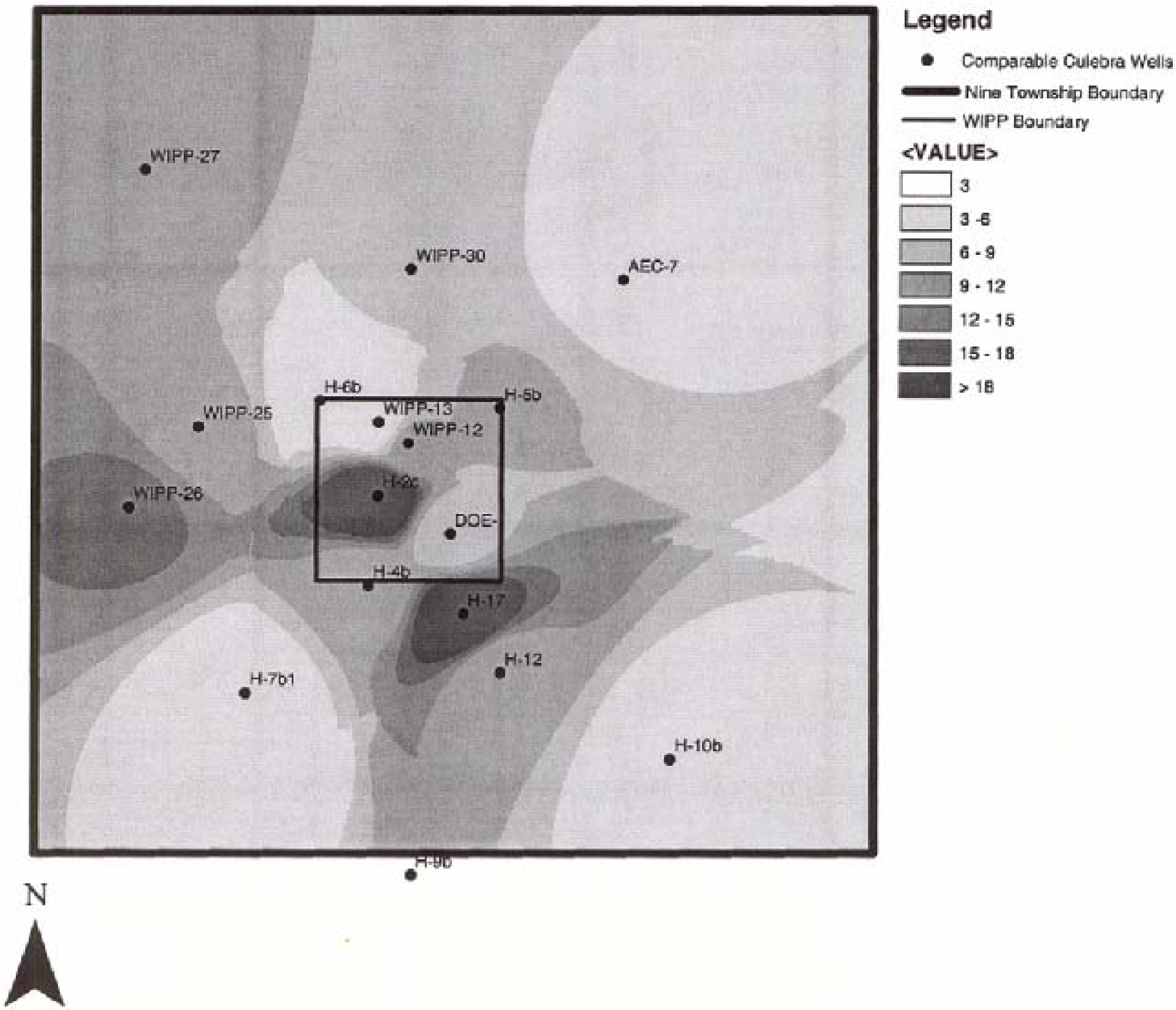


Figure 4
Culebra Head (ft) Difference
CCA to 2001

The workshop developed seven scenarios which could potentially explain the water level changes in the Culebra:

(1) Recharge from potash tailings ponds,
(2) Leakage through wells from shallower units,
(3) Leakage through wells from deeper units (including injection),
(4) Precipitation,
(5) Changes in karst resulting in high-transmissivity conduits,
(6) Mine subsidence,
(7) Subsidence related to oil and gas production.

It is likely that some combination of these seven possibilities would account for the changes in the Culebra water levels. It is unfortunate that the DOE only recently convened this workshop to address these issues, since the water levels have been increasing and have been unexplained for 14 years. Arriving at an explanation for the increases from these (or other) multiple probable causes will undoubtedly take considerable time and may not be satisfactorily answered before the first recertification.

The EEG expressed their concern for the lack of an explanation in 1998 (Neill et al. 1998). Moreover, the EPA expressed concern in 1996:

> "The statement 'they remain unexplained' is insufficient, particularly if the reason for the rise could be interpreted to affect long term hydrologic conditions within the Culebra or be caused by ongoing oil and gas exploration and development activities, such as brine disposal into underlying units" (Trovanto 1996).

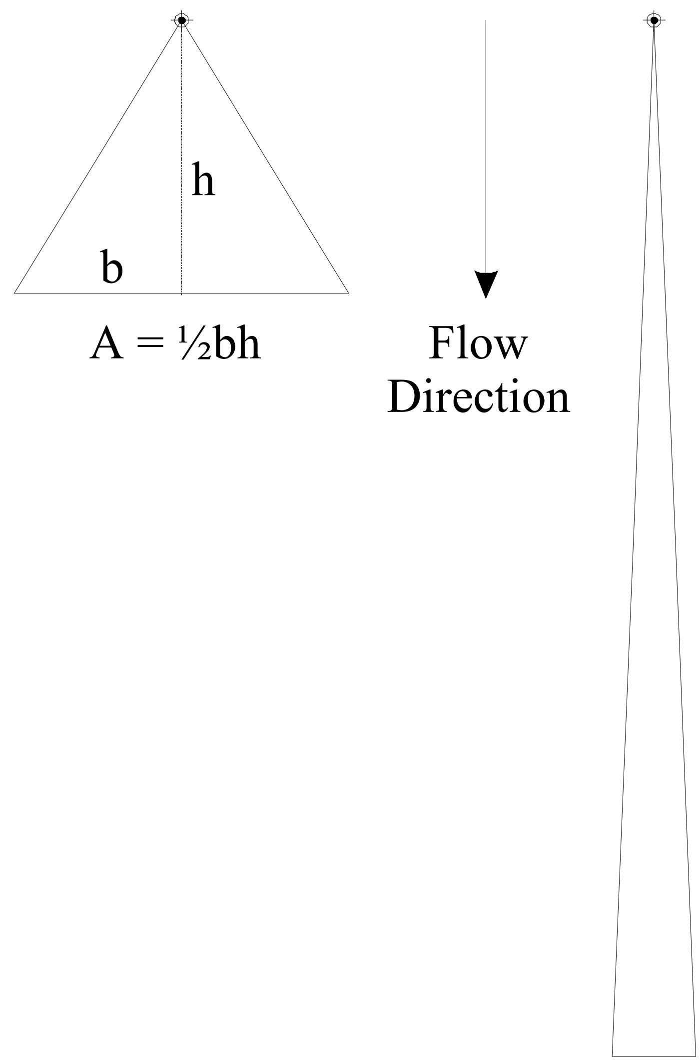
The DOE plans to test the validity of the CCA transmissivity fields using the current water head observations. Since the transmissivity fields were conditioned by both the heads as well as transient response data, it is possible that the fields are still valid given the current observations. If not valid, transmissivity fields will need to be re-generated, possibly using a geology-based method. However, the ability to calibrate transmissivity values does not necessarily validate the conceptual model. Until a source is determined for the water level increases, the validity of the Culebra conceptual model remains in question.

2.4.2 Heterogeneity and Model Discretization

During development of the CCA, several modeling errors were identified which resulted in an artificial spreading in the calculated width of a potential contaminant plume at the expense of its length. This would result in non-conservative travel times to the regulatory boundary. These errors included numerical dispersion and spatial truncation errors in the transport code, poor resolution from using a grid that was too coarse for the scale of the problem, and overestimation of the size of the solute source area (Konikow 1997). These errors are especially apparent in a heterogeneous aquifer such as the Culebra. If a plume spread out laterally due to numerical dispersion, the wider plume will move downgradient a shorter distance than would be the case if a finer grid were used during modeling (Figure 5).

The DOE had planned to address these issues during the recertification (DOE 2001b). The previously used SECO suite of codes were to have been replaced by MODFLOW, STAMMT-L and DTRKCDB. MODFLOW was to have been used for modeling of the flow field. DTRKCDB was to have computed one-dimensional particle velocity paths for input into STAMMT-L. This code incorporates a dual-porosity, multi-rate concept which better addresses heterogeneity and allows for a better representation of the diffusive process. (Haggerty and Gorelick 1995; Haggerty and Reeves 2000).

However, the DOE now plans to retain the SECO models for recertification (Knowles 2002), despite the previously identified problems. In addition, the DOE research on transport in the Culebra showed a superior fit of experimental data with a multi-rate diffusion code such as STAMMT-L (Altman and Meigs 1999). The EEG encourages DOE to reconsider its decision and to implement the previously planned changes to the Culebra models.



Conceptual Diagram Of Contaminant Plumes Represented As Simple Triangles, Showing Different Travel Distances For A Relatively Wide Plume Compared To That Of A Relatively Narrow Plume, Where Both Plumes Encompass Equal Volumes Of Fluid And Equal Masses Of Solute.

Figure 5

Conceptual Diagram of Contaminant Plume Showing Potential For Numerical Dispersion (From EEG-68).

2.4.3 Sampling Procedures for Input Parameters

The co-regionalization of spatial parameters was not considered in the CCA. Hydrogeologic variables that were correlated were sampled independently. This could result in realizations that may be based on unlikely combinations of parameters, and may produce a bias.

For example, transmissivity, fracture spacing, and porosity generally exhibit co-regionalized behavior and are positively correlated (NRC 1996). That is, high transmissivity is related to a higher density of fractures and high porosity. If these correlations are ignored, realizations would be generated that may have high transmissivity, with a low density of fractures and low porosity. While this may still happen under a model of co-regionalization, a higher frequency of realizations representing this scenario will occur under an assumption of variable independence. The EEG recommends an analysis of co-regionalization for spatial variables and co-simulation for those which are highly correlated.

2.4.4 Consistency Between Performance Assessment Models

The connections between some of the performance assessment models and parameters are not always transparent. The EEG had previously recommended that a mass balance be documented to ensure that the fluxes between the various models are coherent (Neill et al. 1998).

For example, it was determined during the 1998 Annual Sensitivity Analysis that BRAGFLO results were skewed by the WSTOCOR term for the corrosion of steel (Helton 1998). In order to represent the hydration of MgO in the analysis, this term was allowed a range of values not representative of the actual steel corrosion process. This linked steel corrosion to hydration of MgO and caused the brine that is associated with the hydration process to disappear, creating mass balance problems. These mass balance problems affected estimated releases from spallings, direct brine releases, and releases through the Culebra.

In the Culebra, actinide transport results from radionuclide releases from brine flow up boreholes that penetrate the repository. In the 1998 Annual Sensitivity Analysis, the brine flows were skewed low because of the large quantities of brine that disappeared. This problem illustrates how nontransparent links between models may produce improper results.

Therefore, it should be demonstrated that the total mass of fluid and solute that the human intrusion borehole model computes to enter the Culebra over 10,000 years should equal the total mass of fluid and solute that is actually added to the Culebra model over the 10,000 year period. This would identify potential problems, increase confidence in the models, and promote an understanding of the performance assessment process.

2.5 Spallings

Spallings consist of repository waste material that experiences failure caused by a rapid reduction of pressure as an intruding drill hole approaches or penetrates the repository. This material would then enter the drilling fluid due to radially channeled, pressurized gas flow from the repository to the lower pressure drill hole. This flow will continue until pressure equilibrium is achieved between the repository and the drill hole. This failed material would then be transported up the drill hole to the surface via gas flow.

The importance of spallings as a potential release mechanism of radionulides into the environment has been demonstrated through the 1996 iteration of the performance assessment calculations. The EEG has consistently stated their concern about the treatment of spallings during the CCA and PAVT analyses (Neill et al.1998; Fairhurst 1998; Silva et al.1999). Neill et al. (1998, pp 57-82) discusses in detail EEG's unresolved issues pertaining to spallings.

The initial spall model proposed by the DOE for the CCA was found inadequate by the conceptual model peer review (Wilson et al. 1996). However, the DOE schedule for submittal left insufficient time for development of a suitable replacement.

The DOE then developed a different model for prediction of radionuclide release. Use of this model predicted much lower releases due to spallings than the original model. However, sensitivity testing by the EEG (Rucker 1998; Silva et al. 1999) revealed instability problems with the model if run outside a range of waste permeabilities between 1.7 to 2.0 x 10^{-13} m^2. The EEG recommended that the DOE begin development of a coherent and straightforward model which characterizes the physical processes of spall (Neill et al. 1998; Silva et al. 1999).

Work has been in progress by the DOE on a new spallings model that was intended for use during recertification (DOE 2001b). This model was to incorporate a modified wellbore hydrualics model with mixing equations for solids and fluids, a drillbit damage model, and a solids transport mechanism up the drill hole annulus (DOE 1999). The stated objective of this new model was to improve predictions of long-term performance (Knowles 1999).

However, the DOE has recently announced that the new model would not be used for recertification performance assessment, but only for an impact analysis (Patterson 2002). The EEG urges the DOE to reconsider the new model's use for the reasons stated above.

2.6 Non-random Waste Emplacement

Waste emplacement practice since the March 1999 opening of the WIPP has demonstrated that random emplacement is not likely. Specific waste streams will be campaigned depending on DOE's agreements with the various states which host TRU waste and the readiness of particular waste streams for shipment from the other sites (DOE 2000).

For example, as of April 22, 2002 (WWIS 2002), the EEG calculated the average radionuclide activity for waste emplaced to date in Panel 1. These calculations indicate that the emplaced activity of ^{239}Pu is 4.24 times, ^{240}Pu is 3.53 times, and ^{241}Am is 5.65 times the projected repository average for the space occupied by waste. Obviously, a future intrusion into Panel 1 would result in a different potential release than from a panel in which average radionuclide activities were emplaced.

In the CCA performance assessment, under a random emplacement assumption, the contents of a waste container removed by cuttings and cavings were randomly sampled from 569 separate waste streams. A drill hole intruding a room and intersecting each of three stacked containers would have resulted in each of the three containers being randomly sampled with the probability of hitting a particular waste stream weighted according to its relative quantity. However, in reality it is likely that all three containers would be from the same waste stream.

It has been previously demonstrated by the DOE that non-random emplacement could increase the mean release values (Dials 1997). The EEG recommends that the DOE develop a waste loading plan based on their shipment schedule. While this schedule will certainly change over time, it is the best information currently available and presents a more realistic assumption than random waste emplacement. All intrusion scenarios could then consider non-random emplacement, providing better estimates of releases in brine, cuttings, cavings, and spallings.

3.0 CONCLUSIONS

Performance Assessment is an iterative process that should incorporate the best understanding of all of the integrated components at the time it is being done. For recertification, this "best understanding" may translate into modifications of conceptual models based on ongoing research or operating experience gained during the emplacement of waste. It may also mean consideration of scenarios that were previously screened out, but may warrant inclusion because of new information or to allay public concern.

In accordance with 40 CFR 194.15(a), the DOE must present an updated performance assessment with the CRA. This performance assessment must describe relevant new information and system changes since 1998 (Marcinowski 2002). The DOE had planned to submit several changes that would have addressed some of the ongoing unresolved issues presented in this report. However, the DOE has now modified their plans and are proposing minimal changes to the conceptual models for the first recertification. This change in plan likely coincides with the EPA's guidance found in the above mentioned letter, "Some of the changes currently included as part of the Technical Baseline Migration may necessitate a rulemaking to modify our Certification Decision." The DOE has allowed insufficient time for submission of planned changes that may require a rulemaking.

However, some of the withdrawn changes may reflect new information. These include:

(1) Continuing changes to the Culebra water levels and their reflection on the validity of conceptual model,
(2) Interpretation of Culebra tracer tests demonstrating the superiority of a multi-rate diffusion code,
(3) Improved characterization of the physical process of spall using an improved model,
(4) Experience indicating the non-random emplacement of waste.

Other planned changes such as the use of EQ3/6 instead of the FMT model would have improved public confidence. In addition, public confidence in the performance assessment process would be enhanced through serious consideration of fluid injection and solution mining scenarios.

Issues involving actinide chemistry and the Culebra modeling will likely be ongoing issues. Well-planned research programs should be conducted to adequately address their effect on long-term repository performance. For example, in actinide chemistry the EEG recommends the development of a conceptual kinetic model for solubility. For the Culebra, a three-dimensional, regional hydrogeological model should be developed to facilitate understanding of the relationship between hydrogeological units. Such a model would be useful in determination of the Culebra water elevation increases.

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APPENDIX A

Resolution of the Long-Term Performance Issues at the Waste Isolation Pilot Plant

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Resolution of the Long-Term Performance Issues at the Waste Isolation Pilot Plant

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The Waste Isolation Pilot Plant (WIPP) is a geological repository for disposal of U.S. defense transuranic radioactive waste. Built and operated by the U.S. Department of Energy (DOE), it is located in the Permian age salt beds in southeastern New Mexico at a depth of 655 m. Performance assessment for the repository's compliance with the 10,000-year containment standards was completed in 1996 and the U.S. Environmental Protection Agency (EPA) certified in 1998 that the repository meets compliance with the EPA standards 40 CFR 191 and 40 CFR 194. The Environmental Evaluation Group (EEG) review of the DOE's application for certification identified a number of issues. These related to the scenarios, conceptual models, and values of the input parameters used in the calculations. It is expected that these issues will be addressed and resolved during the first 5-year recertification process that began with the first receipt of waste at WIPP on March 26, 1999, and scheduled to be completed in March 2004.

KEY WORDS: WIPP; radioactive waste; repository; performance assessment; transuranic waste.

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a geological repository built by the U.S. Department of Energy (DOE) for the disposal of defense transuranic (TRU) waste in bedded salt, at a depth of 655 m, about 40 km east of Carlsbad, New Mexico. The DOE submitted its compliance certification application (CCA)[(1)] to the U.S. Environmental Protection Agency (EPA) on October 29, 1996. EPA certified that the facility met the EPA Standards[(2)] and Criteria[(3)] for the disposal of TRU waste on May 18, 1998.[(4)] The waste bound for WIPP contains chemically hazardous materials regulated by the Resource Conservation and Recovery Act (RCRA) in addition to the radioactive components. A RCRA permit from the New Mexico Environment Department (NMED) is therefore required for WIPP in addition to certification by the EPA. The NMED is expected to announce its decision on the RCRA permit in October 1999. The WIPP began receiving nonmixed TRU waste on March 26, 1999.

The EPA certification required the DOE to provide a performance assessment (PA) of the repository. Performance assessment is defined in the Standards[(2)] as an analysis that:

1. Identifies the processes and events that might affect the disposal system.
2. Examines the effects of these processes and events on the performance of the disposal system.
3. Estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

The EPA disposal standards contain four re-

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quirements: the containment requirements, assurance requirements, individual protection requirements, and groundwater protection requirements. Performance assessment is used to determine compliance with each of these except for the assurance requirements. The assurance requirements were intended to compensate for the inherent uncertainty in a 10,000-year projection of events.

The performance assessment requires the (1) development of potential scenarios for release of radionuclides to the environment, (2) screening of all features, events, and processes, and the combination of features, events, and processes that may affect the disposal system, (3) identification and selection of the most appropriate conceptual models, (4) selection or development of appropriate computer codes, (5) determination of the input parameters for the analyses, and (6) calculation of the cumulative release in the form of complementary cumulative distribution functions.

The DOE has analyzed the probabilities and quantities of radionuclide releases to the environment for the undisturbed repository and the repository inadvertently disrupted by drilling. The outcome of the performance assessment is controlled by the conceptual models and the values for the input parameters used. These include gas pressurization, mechanics of human intrusion, characteristics of the waste including actinide solubility, mechanics of rock fracturing, and retardation processes in actinide transport through the overlying aquifer. The numerical values of the parameters are ideally determined by scientific investigations in the laboratory and/or the field.

Various iterations of the WIPP performance assessment were published from 1990 to 1992.[5–7] The 1996 PA may thus be viewed as an iteration in this ongoing process. Recertification for compliance is required at least every 5 years after first receipt of waste. The first recertification is due in March 2004. In addition to the 5-year recertification cycle, the DOE must submit periodic reports on any activities or conditions at the WIPP that differ significantly from the information contained in the most recent compliance application. The EPA may also, at any time, request additional information to determine whether the certification must be modified, suspended, or revoked. Hence, the EPA certification requires continued scientific investigation and technical review.

The Environmental Evaluation Group has reviewed[8] the scientific effort leading to certification. This paper summarizes the major technical issues identified by the certification process, the status of each issue, and a course of action for resolution as part of the recertification. Limited computations to examine the impact of these issues were published by EEG in 1998.[9]

2. THE ENVIRONMENTAL EVALUATION GROUP

The Environmental Evaluation Group (EEG) was created in 1978 to provide a full-time independent technical review of the WIPP to ensure protection of the public health, safety and the environment of New Mexico. The impact of EEG on previous PA efforts can be seen in the following areas:

1. Continuation[10] of performance assessment work after the disposal standards were vacated by the court in 1987, thus not losing time when the standards were repromulgated in 1993.
2. The DOE decision to abandon the *in situ* experiments with TRU waste at WIPP and redirect its efforts toward completing the performance assessment calculations and obtaining EPA certification.[11]
3. DOE's experimental programs to obtain data for parameters such as actinide solubility and retardation.
4. EPA's Criteria and Guidance for the WIPP.[12,13]
5. DOE's PA analyses.[14,15]
6. Testing the sensitivity of the PA models to various parameters including the borehole intrusion rate, actinide solubility, chemical retardation, the presence of a brine reservoir, and subsidence due to mining.[9]

3. GEOHYDROLOGICAL SETTING OF WIPP

The WIPP repository is located in the northern part of the Delaware Basin that is well known for its thick sequence of Permian age evaporites and economic deposits of potash and hydrocarbons (oil and gas). Figure 1 shows a geologic cross section at the center of the WIPP site. The repository is located at a depth of 653 m in the lower part of the approximately 610-m-thick Salado Formation, consisting of bedded salt (halite) and interbeds of anhydrite and

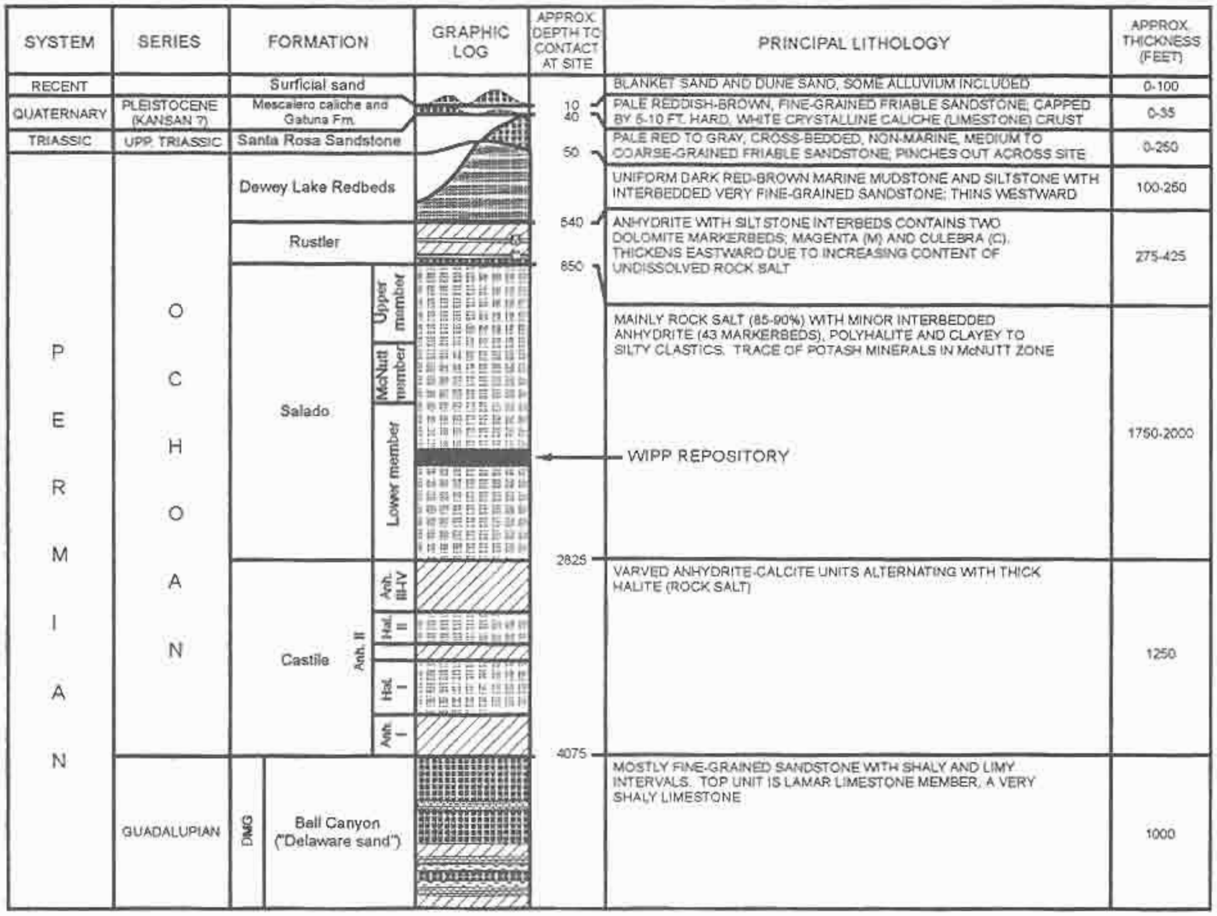

Fig. 1. Gereralized stratigraphy at the WIPP site.

clay. The upper part of the Salado Formation contains a 122-m-thick zone rich in potash minerals known as the McNutt Potash Member. The bottom of this zone is approximately 122 m above the WIPP repository. A 95-m-thick Rustler Formation overlies the Salado and it contains two 8.6-m-thick fractured dolomite water-bearing zones, the Magenta and the Culebra. The more permeable Culebra is considered to be a potential pathway for migration of radionuclides to the biosphere in case of a breach of the repository. The Culebra aquifer is about 435 m above the repository.

The Castile Formation underlies the Salado and its upper unit consists of varved alternating layers of anhydrite and calcite. At least 27 boreholes within 16 km of the WIPP site have encountered pressurized brine in this unit, about 244 m below the repository level (Fig. 2).

The 6.4 km × 6.4 km WIPP site is situated in a region rich in potash, oil, and gas. There were 163 producing oil and gas wells in a 3.2-km zone surrounding the WIPP site at the end of 1998 (Fig. 3). The nearest production of potash is currently about 2 km from the southwestern corner of the site, although potash leases are held immediately surrounding the WIPP site. Drilling for oil and gas through the potash reserves is restricted until potash mining is completed.

4. ISSUES TO BE RESOLVED

The geohydrologic conceptual models for WIPP and the issues associated with them have been described by Chaturvedi and Anderson.[16] Many conceptual models are presented in the CCA.[1] The EEG raised issues with a number conceptual models during the WIPP certification process. Similarly, several issues relate to the values of the input parameters used in the CCA. The EEG looks forward to resolution of these issues during the recertification process.

4.1. Conceptual Model of the Castile Pressurized Brine Reservoir

Within a few miles of the WIPP site there are at least 27 reported encounters of pressurized brine in the upper anhydrite layer of the Castile Formation (Fig. 2). Two of these encounters (ERDA-6 and WIPP-12) were in the WIPP project boreholes and the rest have been reported by oil and gas drilling companies. When borehole WIPP-12, located within the WIPP site, hit brine at a depth of 920 m, brine started flowing out of the well at a rate of 22 liters/sec and more than 8 million liters of brine were unavoidably produced during drilling, logging, and between testing.[17] Based on an extensive series of flow tests, the brine reservoirs penetrated by the WIPP-12 and ERDA-6 boreholes were estimated to contain 2.7 billion and 100 million liters of brine, respectively. The different pressure potentials and geochemical data from the two encounters suggested a lack of communication between the ERDA-6 and WIPP-12 brine reservoirs. There was no consensus on the origin and the age of the brine reservoirs.

The originally planned configuration of the WIPP repository and the WIPP experimental areas would have brought the waste within 140 m south of the WIPP-12 borehole. The EEG recommended moving the repository in 1982 and the DOE rotated the repository configuration to relocate the nonwaste experimental area to the north and the repository itself 2 km south of WIPP-12. In 1983, EEG proposed geophysical investigations to delineate the extent of pressurized brine in the Castile Formation underlying the WIPP site and particularly under the new location of the repository. Time-domain electromagnetic (TDEM) geophysical survey was conducted by the DOE above the WIPP repository in 1987, and the results gave a clear indication of the presence of brine under the WIPP repository.[18]

There are two areas of clustered brine encounters, northeast and east of the WIPP site (Fig. 2). The DOE used geostatistical modeling to ascertain the probability of pressurized brine directly below the repository. A correlation length of clustered brine encounters represents the average size of a brine reservoir in the Delaware Basin. Brine encounters are defined by reports of intersection of pressurized brine filed by the drillers to the State of New Mexico. All wells without a report of pressurized brine were considered to not have intercepted brine. The data on brine encounters during commercial drilling for

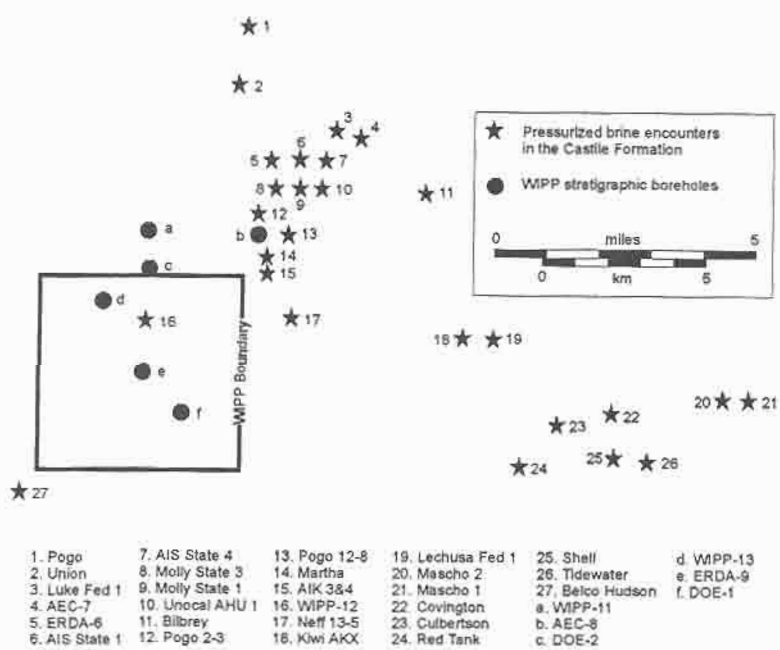

Fig. 2. Boreholes reported to have encountered pressurized brine in the upper Castile Formation in the vicinity of WIPP.

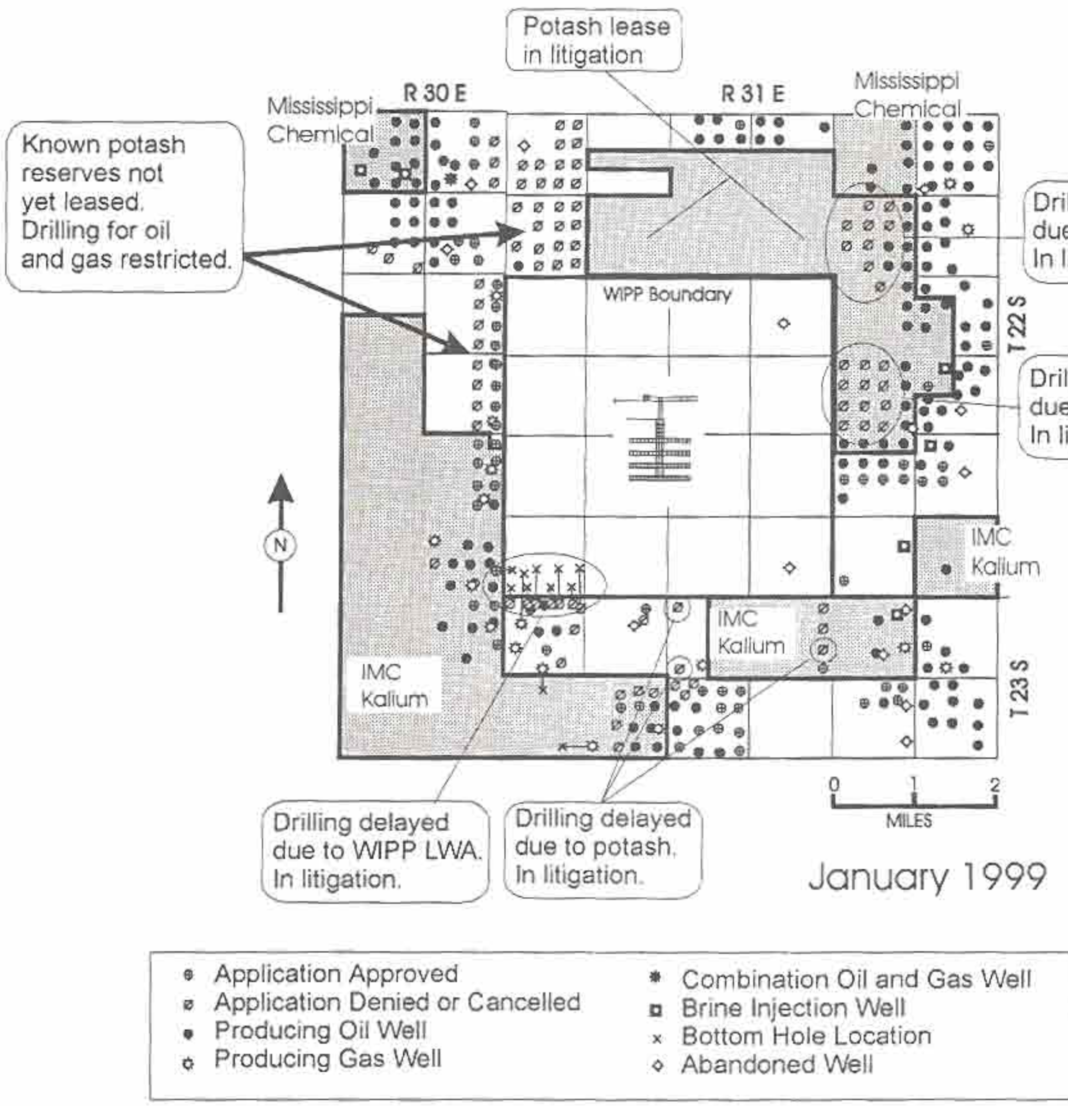

Fig. 3. Current interest in potash, oil, and gas resources surrounding the WIPP.

oil and gas contain no information on testing for the size of the brine reservoir. The DOE used the estimate of correlation length to determine the probability of the WIPP-12 brine reservoir extending below the repository to be 8%.

The best interpretation of the pore volume of the WIPP-12 brine reservoir is 2,700,000 m^3.[17] Assuming the maximum thickness of 24 m[19] for the anhydrite layer containing the brine, a porosity of 0.008 (mean value in the CCA), and a pore compressibility of 10^{-10} Pa^{-1}, the radius of a circle representing the footprint of a cylinder of brine reservoir is 2 km (Fig. 4). Constrained by several boreholes in which brine was not encountered , such a circle easily envelopes the entire repository.

Given the magnitude of the brine reservoir encountered by WIPP-12 and the results of the TDEM survey,[18] it appears logical to assume that the reservoir intercepted by WIPP-12 extends under the WIPP repository. The 8% probability of a future borehole at the WIPP repository encountering brine in the Castile Formation, assumed in the CCA,[1] therefore remains unjustified.

The CCA proposed a brine encounter of 8% based on the argument that the brine resides in subvertical fractures that have an 8% probability of en-

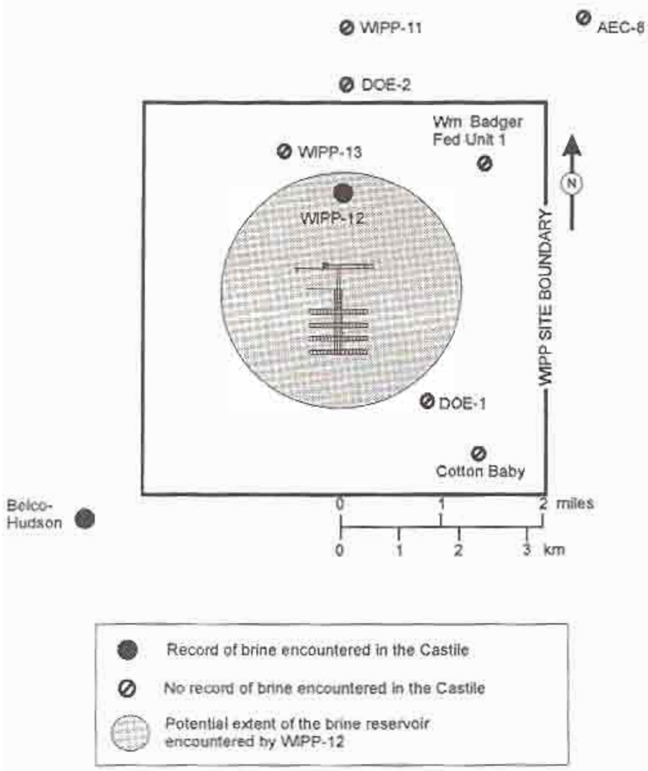

Fig. 4. Potential extent of WIPP-12 brine reservoir using WIPP-12 pressure recovery data, rock compressibility of 1×10^{-10} Pa^{-1}, and reservoir thickness of 24 m.

counter by a vertical drill hole. The EEG recommended a 100% probability on the basis that the WIPP-12 brine reservoir was large enough to extend underneath the repository, a conclusion also confirmed by geophysical testing directly above the repository. The TDEM data may be interpreted to indicate the brine to be under 60% of the repository. The EPA agreed that 8% was not representative and decided that the probability should be sampled from a range of 1% to 60%. There is no technical basis for the 1% value nor does it make sense to use the probability of a probability. A fixed value of 60% should be used in recertification calculations.

The CCA assumes a pore volume of the brine reservoir underlying the repository to vary from 32,000 to 160,000 m^3. The much lower volume is partly based on the unjustified assumption that the parts of the reservoir extending beyond the repository will get depleted by multiple intrusions in the area outside the repository. Thus, both the probability and the volume of the potential brine reservoir underlying the repository have been grossly underestimated in the CCA.

The EPA Performance Assessment Validation Test (PAVT) required the calculations to be repeated assuming a brine volume of 17 million m^3. The increased volume had a noticeable effect on releases, but compliance was still met. From this calculation, the EPA suggested that the PAVT justified the original CCA brine reservoir parameters as adequate for use in PA. The calculation does not justify this conclusion. There are many other parameter values and conceptual and numerical models that may be changed and these changes will affect the outcome of future calculations. There is no rational basis for finding an unjustified value to be acceptable unless it is justified based on observations, experiments, or widely known facts.

4.2. Radionuclide Transport Through the Culebra

Transport of radionuclides to the accessible environment through the Culebra dolomite aquifer overlying the repository has been postulated to be the major pathway for breach of the WIPP repository. The EPA concluded that the very low contribution to the total releases from this pathway, as calculated in the CCA, was due to the assumed values for chemical retardation (K_d). In fact, the calculated low releases from the groundwater pathway are due to a number of assumptions made in the CCA. The amount of radionuclides introduced in the Culebra is low due to the assumptions of actinide solubility, brine reservoir characteristics, and the intrusion borehole characteristics. There are other factors in calculating transport through the Culebra besides the assumption of K_d values that result in low releases. These factors are discussed below.

The National Academy of Sciences WIPP Committee (Chapter 6 and Appendix F of Ref. 20) raised a number of issues regarding the conceptual model and numerical model of transport through the Culebra aquifer. These issues do not appear to have been addressed by the EPA in the certification decision. Neither the EPA's "Technical Support Document for 194.23: Ground Water Flow and Contaminant Transport Modeling at WIPP" nor the "Compliance Application Review Document (CARD) No. 23: Models and Computer Codes" directly address these issues. These issues are described in detail by EEG[9] and are summarized below.