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EVALUATION OF THE WIPP PROJECT'S COMPLIANCE WITH THE EPA RADIATION PROTECTION STANDARDS FOR DISPOSAL OF TRANSURANIC WASTE

Robert H. Neill
Lokesh Chaturvedi
Dale F. Rucker
Matthew K. Silva
Ben A. Walker
James K. Channell
Thomas M. Clemo

Environmental Evaluation Group
7007 Wyoming Blvd., NE, Suite F-2
Albuquerque, New Mexico 87109

and

505 North Main Street, P.O. Box 3149
Carlsbad, New Mexico 88221-3149

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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. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository 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 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, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

Robert H. Neill
Director

EEG STAFF

Sally C. Ballard, B.S., Radiochemist
William T. Bartlett, Ph.D., Health Physicist
Radene Bradley, Secretary III
James K. Channell, Ph.D., Environmental Engineer/Health Physicist
Lokesh Chaturvedi, Ph.D., Deputy Director & Engineering Geologist
Patricia D. Fairchild, Secretary III
Donald H. Gray, M.A., Environmental Specialist
Jim W. Kenney, M.S., Environmental Scientist/Supervisor
Lanny King, Assistant Environmental Technician
Betsy J. Kraus, M.S., Technical Editor/Librarian
Robert H. Neill, M.S., Director
Dale F. Rucker, M.S., Performance Assessment Engineer
Jill Shortencarier, Executive Assistant
Matthew K. Silva, Ph.D., Chemical Engineer
Susan Stokum, Administrative Secretary
Ben A. Walker, B.A., Quality Assurance Specialist
Brenda J. West, B.A., Administrative Officer

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Betsy Kraus prepared the references. The contributions of Jill Shortencarier, Patricia Fairchild, and Susan Stokum who patiently and diligently provided secretarial support through a number of drafts of this multi-authored report are also gratefully acknowledged.

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EXECUTIVE SUMMARY

SCOPE OF THE EEG REPORT

The U.S. Environmental Protection Agency's (EPA) proposed rule to certify that the Waste Isolation Pilot Plant (WIPP) meets compliance with the long-term radiation protection standards for geologic repositories (40CFR191 Subparts B and C), is one of the most significant milestones to date for the WIPP project in particular, and for the nuclear waste issue in general. The Environmental Evaluation Group (EEG) has provided an independent technical oversight for the WIPP project since 1978, and is responsible for many improvements in the location, design, and testing of various aspects of the project, including participation in the development of the EPA standards since the early 1980s. The EEG reviewed the development of documentation for assessing the WIPP's compliance by the Sandia National Laboratories following the 1985 promulgation by EPA, and provided many written and verbal comments on various aspects of this effort, culminating in the overall review of the 1992 performance assessment (Lee, et al., 1994). For the U.S. Department of Energy's (DOE) compliance certification application (CCA), the EEG provided detailed comments on the draft CCA (Neill, et al., 1996) in March, 1996, and additional comments through unpublished letters in 1997 (included as Appendices 8.1 and 8.2 in this report). Since the October 30, 1997, publication of the EPA's proposed rule to certify WIPP, the EEG gave presentations on important issues to the EPA on December 10, 1997, and sent a December 31, 1997, letter with attachments, to clarify those issues (Appendix 8.3). The EEG also presented its views to the DOE and the EPA at a number of meetings during the course of the proposed rule development. Since the publication of the proposed rule, the EEG staff met with the EPA staff on 12/10/97, 1/22/98, and 1/26/98; and with the DOE technical staff and contractors on 1/21/98 (EPA/DOE meeting to which EEG was invited), and on 2/17/98 and 2/20/98.

CONCLUSION

The EEG understands and appreciates the large amount of work that the EPA staff and consultants have accomplished in a very short time, as did the DOE staff and consultants in preparing the CCA. However, the EEG has raised a number of questions that may have an impact on compliance. The impact of these questions on the compliance must be assessed or resolved through additional information, experimentation, or modeling. Unless these issues are satisfactorily resolved, the EPA should conduct another performance assessment calculation using the parameter values and models that are properly justified. EPA should base its compliance certification decision on the results of these new calculations. It is essential that this first repository's predicted behavior instill a high degree of public confidence.

Although the EPA standards require demonstration of compliance only for 10,000 years, some partial calculations performed by the EEG indicate that higher releases may be predicted beyond that period (see Sections 2.9.3 and 2.14.1 of this report). There is no strong justification for stopping the calculation at 10,000 years. The EEG recommends performance of representative calculations to assess the behavior of the repository beyond 10,000 years.

The WIPP repository, as planned, does not have sufficient multi-barrier protection which is a fundamental international design philosophy for a nuclear waste repository. The EEG recommends EPA require DOE to examine the existing plans for processing and repackaging the waste at its weapons complex, and incorporate in the WIPP design at least those reprocessing and repackaging features which have been planned. This will provide at least some degree of multi-barrier assurance to WIPP.

GENERAL ISSUES

Lack of Feedback From EPA

In spite of the best efforts by the EEG, the EPA reaction to our reviews and suggestions has been slow and apparently driven by legal considerations. This is not a criticism of the EPA, but simply a statement of fact. For example, the EEG and the EPA staff met on June 17, 1997, to discuss the basis for the new parameter values that the EPA had recommended to the DOE for a new set of performance assessment validation test (PAVT) calculations. At this otherwise very productive meeting, the issue of actinide solubility assumptions could not be resolved because the EPA did not have its expert consultant at the meeting and the EPA could not share the technical support document with EEG until it was released as a part of the proposed rule in late October, 1997. When the EEG expressed continued disagreement on this issue with the EPA at the meetings in December, 1997 and January, 1998, the EPA asked EEG to wait until the final rule is promulgated in May, 1998, to get another explanation, rather than discussing the matter at those meetings with its experts. The EPA practice of not identifying the commenters in their responses and combining comments by various individuals and groups makes it further difficult to identify the response to our comments. The net result of this process is that there may be issues included in this report for which the EPA may have valid responses but those will not be available to the EEG until the final rule is promulgated.

Excessive Reliance on DOE

One general impression of the EPA's proposed rule is that the EPA relied heavily on the DOE submissions and rebuttals to reviewers' comments, and sufficient attention does not appear to have been paid to the comments by the reviewers. Serious technical questions with regard to the conceptual models, selected values of input parameters in the calculations, and interpretation of scientific experiments have been raised by the EEG, the National Academy of Sciences Committee on WIPP, the NEA/IAEA International Review Group, and several environmental groups. The proposed rule has, however, accepted the DOE viewpoint on most of the issues, sometimes without any questions, and others after minor clarifications. For example, the EEG has had a longstanding concern about the values used for the chemical retardation parameter, K_d, used in modeling radionuclide transport through the Culebra aquifer overlying the repository. The EEG and the DOE organized a one day meeting in Albuquerque on July 30, 1997, to discuss this issue. The EPA was invited and attended this meeting. Four weeks after the meeting, both the DOE and the EEG submitted letters to the EPA's WIPP docket about this issue. In discussing this issue, the EPA's proposed rule documents extensively discuss and quote from the DOE letter, but do not even acknowledge the existence of the EEG letter in the docket. To provide another example, the NEA/IAEA International Review Group raised a number of questions about the need to more carefully predict the physical and chemical implications of the magnesium oxide backfill. The EEG has questioned a number of assumptions about the repository conditions, which are based on insufficiently justified assumptions on the effect of MgO on the repository. But the EPA has accepted the DOE assumptions without providing sufficient reasons to not address the NEA/IAEA International Review Group and the EEG questions and recommendations.

Apparent Neglect of Uncertainties
Another disturbing aspect of the EPA's proposed rule is the confidence that has been expressed for assumptions that are clearly based on a number of uncertainties. For example, the EPA has rejected the EEG's suggestion for considering the "stuck pipe" and "gas erosion" scenarios for calculating releases, by the argument that the waste permeability may be as low as 5.3×10^{-15} m^2, but will not be 1×10^{-16} m^2. A value of 1×10^{-16} m^2 is used in the Compliance Certification Application (CCA) as the upper limit for which the stuck pipe/gas erosion process should be considered, but it was based on the rejected spallings code. It is a well established fact that the permeability of the waste is a highly variable and uncertain parameter due to the highly heterogeneous nature of the waste. In fact, the OECD/IAEA International Review Group felt strongly enough about the heterogeneity issue that they included it as one of the two main issues in the cover letter forwarding the report to the DOE.

Increasing Unwarranted Uncertainty Assumptions
On some issues where there is a reasonable data base to make certain straightforward assumptions, the EPA has chosen to widen the margin of uncertainty in the calculations. A case in point is the probability of a future borehole encountering a brine reservoir in the upper Castile Formation underlying the repository. Based on the number of boreholes drilled versus those that reported encountering brine in the northern Delaware Basin, the DOE suggested a probability of 8%in the CCA. The EEG argued that since the borehole WIPP-12 at the WIPP site encountered brine and was extensively tested and was estimated to contain 700 million gallons of brine, any borehole drilled at the repository should be assumed to encounter brine. The EPA argued that the geophysical survey at the site indicates that up to 60% of the area under the repository may be underlain by brine, but then used a range of probability of 1% to 60% in the new PAVT calculations. The EEG sees no justification for this arbitrary spread of the probability range. To argue that this parameter does not make a difference in the calculated releases avoids the question, rather than answer it.

Use of Partial Sensitivity Analyses
It is a known fact that in a probabilistic consequence analysis with a large number of variables, the calculations are sensitive to a large number of parameters. There is doubtless varying degree of sensitivity of calculations to various parameters, but the rational way to get the most reliable results is to determine the value of each parameter as accurately as possible, and then run the calculations. The EPA has, on the other hand, argued that when a parameter value used in the CCA is not otherwise justified, but the compliance is still met with a new value, then the CCA value is "adequate". For example, changing the assumed brine volume of a Castile brine reservoir from 160,000 cubic meters (in the CCA) to 17 million cubic meters (in the PAVT calculation) had a noticeable effect on releases, but the compliance with the standards was still met. However, "EPA believes that the PAVT verifies that the original CCA Castile brine reservoir parameters were adequate for use in PA and comparison against the radioactive waste containment requirements." (U.S. EPA, 1997c, p. 58800). The EEG strongly rejects this argument because there are many other parameter values and conceptual and numerical models that should be

changed unless acceptable justification can be provided for the assumptions in the CCA and the proposed rule; and these changes will change the outcome of calculations. To declare an assumed value that is not otherwise justified "adequate" on the basis of limited changes in other values is, at the least, premature. 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.

Faulty Sampling Ranges
The CCA appears to have argued in some cases that if the sampled distribution of a parameter used in the CCA calculations is in error, but includes the likely values of that parameter, then the CCA calculations are acceptable. The EEG disagrees with this approach. Under these conditions, the CCA calculations should be repeated with the best estimate of the parameter distributions available. The use of a faulty distribution of one parameter biases the Complementary Cumulative Distribution Function (CCDF) curves and confuses the assessment of uncertainty. The use of more that one faulty parameter set makes the assessment of uncertainties impossible because of the complex non-linear nature of the performance assessment models. This issue is discussed further in the Section "Faulty Sampling Ranges" in Appendix 8.2 of this report.

Insufficient Scrutiny for DOE Submissions
In many instances, the EPA appears to have accepted the DOE arguments without sufficient independent scrutiny. For example, the EPA agrees with the DOE's assessment that the borehole ERDA-9, which is located in the underground development area and connects the upper Castile Formation with the ground surface, is not significant to the repository's performance assessment and may be "screened out" of consideration. The basis of this concurrence with the DOE is that, "ERDA-9 did not penetrate an area that will become a waste panel and DOE has indicated that abandoned boreholes more than a meter away from the waste can be screened out of PA due to low consequence." (U.S. EPA Proposed Rule, Federal Register, vol. 62, no. 210, p. 58801). The EPA apparently did not investigate that the basis of the 1 meter criterion is the assumed difference in permeability of the disturbed versus the undisturbed rock zone surrounding the excavations, which can be changed by assumptions of less drastic change or an intermediate transition zone. Also, the EEG has not been able to find a reference to the exact location of the ERDA-9 borehole *at the repository horizon.* It is common knowledge that the boreholes are never drilled completely vertical. In fact, a WIPP project borehole, H-19B4, drilled in 1995 to exacting specifications under the guidance of the Sandia National Laboratory hydrologists, deviated 9.5 meters (31 feet) in a vertical depth of 229 meters (752 feet); there was every reason for that test hole to be as vertical as possible. At that rate, a borehole may deviate 27 meters (89 feet) in 655 meters (2150 feet, the depth to the repository) depth. To dismiss the potential impact of ERDA-9 without asking these questions and without requiring any special plugging and sealing in this borehole is difficult to understand.

SPECIFIC ISSUES
The EEG agrees with a number of changes that the EPA required in conducting the PAVT calculations, but believes that another set of calculations needs to be performed with the changes outlined in the following paragraphs.

Solubility
The solubility of actinides is very important to calculating the releases from the repository. The CCA uses a model known as FMT to calculate these solubilities. EEG found that the model predicts differences for actinide sulfate solubilities that cannot be explained by chemistry, thus raising questions about the reliability of this model.

Rather than using an extensive plutonium data base, the FMT predictions relied on thermodynamic data for other elements and an oxidation state analog argument. EEG recommends that the calculations be performed using data for plutonium and the values for solubility and complex ion formation contained in the peer-reviewed data compilation by the Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA).

EEG agrees with EPA's documentation of the shortcomings of the solubility uncertainty ranges advanced by DOE. However, EEG questions EPA's argument that the ranges are adequate. As noted by EPA, there is a lack of data to determine the uncertainty ranges for oxidation states IV and VI. EEG recommends that the uncertainty range needs to be determined with the appropriate plutonium data.

In the solubility calculations, the CCA inappropriately discounts the role of organic ligands on plutonium solubility by arguing that EDTA is the strongest complexing agent and there is not enough amount present in the inventory to make a difference. But citrate forms very strong complexes with actinides in the +4 oxidation state and very weak complexes with other cations. Thus, the solubility of a stable plutonium-citrate complex in individual waste containers needs to be calculated.

There are serious unanswered questions about the impact of magnesium oxide backfill on the solubility of the actinides. It is proposed that magnesium oxide will reduce the solubility of the actinides by controlling the pH. But, it is not known how long the early reaction product, nesquehonite, will persist. The FMT model calculates that the presence of nesquehonite drives the solubility of the +4 actinides, such as plutonium, higher than in the no backfill case. This requires further investigation.

Spallings
The CCA spallings model was rejected by the DOE's peer review after submission of the CCA, but a new coherent model and a computer code that calculates the projected releases has not been developed. The EEG finds the basis of accepting the predicted release volumes due to spallings as determined by the CCA to be both unnecessarily convoluted and faulty. Since this is a mechanism for the largest projected releases from the repository, it is essential that it is treated through defensible conceptual and numerical models.

Air Drilling
The air drilling scenario proposed by Dr. John Bredehoeft was rejected on the basis of regulation, despite records of such drilling in the Delaware Basin. Low probability and low consequence are also discussed in EPA's Air Drilling Analysis (U.S. EPA, 1998), and the scenario was ruled out again. However, the EEG does not believe that the issue has been resolved. Neither EPA nor

DOE examined drilling records in the Texas portion of the Delaware Basin. New developments in underbalanced drilling also inhibit a full understanding of the capabilities of this expanding technology. The EPA's analysis of low consequence, in which a spread sheet model was used, has serious shortcomings.

Fluid Injection

For fluid injection activities adjacent to the site, the EPA has accepted a "low consequence" argument based on a model that has not been verified with oil field water flood data, despite the availability of such data. EPA offers a "low probability" argument based on its expectations of fluid injection practices, although DOE maintains that the probability of future fluid injection practices would be difficult to define. The low probability argument has not been reconciled with the common observation of water flowing through the Salado Formation in water flood operations throughout southeast New Mexico. Neither the DOE nor the EPA have adequately addressed concerns about future CO_2 flooding in the vicinity of WIPP. The basis for dismissing the Rhodes -Yates incident does not reflect a review of the technical information presented in that case. DOE has not explained the anomalous water level rises that have been observed for the last ten years in the Culebra aquifer despite the documented concerns of EEG, EPA and the National Academy of Sciences (NAS) WIPP Committee. EEG recommends additional effort to explain the Rhodes-Yates water flooding incident, if the most obvious explanation of flow of large quntities of water through the Salado interbeds is not acceptable to the EPA and the DOE. The fluid injection scenario cannot be dismissed either on the basis of low consequence or low probability.

Anhydrite Fracturing

The EEG has reviewed the basis of the anhydrite fracture model used in the BRAGFLO code and has a number of questions about its validity. The model is unusual in that the effect of fracturing is treated using an equivalent porous medium. All the relevant literature examined by EEG treat fractures as distinct porosity. Use of an equivalent porous medium is not in itself unreasonable. However, the DOE has not referenced, nor has the EEG been able to find, a description of similar treatment of the dependance of porosity and permeability on pressure as a result of fracturing. The lack of a clear development of the BRAGFLO model from established models makes its review difficult. The EPA should request that the anhydrite fracture model of BRAGFLO be compared to the treatment of fracture development in hydrofracing codes commonly used in the industry. Until the model and its assumptions are properly justified, the EEG finds it difficult to accept the results derived from this model.

Solution Mining

EPA's conclusion that potash solution mining is not likely at WIPP relies on solicited comments that are factually incorrect and inconsistent with the published scientific literature. DOE and EPA maintain that excavation mining captures the effects of solution mining on the hydraulic conductivity of the overlying aquifers. However, based on the scientific literature, the prediction of subsidence above solution mines can be much more complex than the prediction of subsidence due to excavation mining. It appears to be incorrect to calculate a probability of mining based on past potash production, which was inherently dependent on past mineral economics and the availability of high grade ore. Potash is used by the fertilizer industry and is ultimately used for the production of food. It seems reasonable to assume that the demand for food will continue and low grade potash ores will eventually be mined to meet this demand.

Groundwater Flow and Radionuclide Transport Through the Culebra

A number of questions related to the flow and transport through the Culebra have been identified by the EEG and the National academy of Sciences WIPP Committee that have not been addressed by the EPA. These questions relate to the conceptual models of the origin and flow of water in the Culebra aquifer, modeling of transport through the Culebra, and the justification of the assumed values of the chemical retardation parameter (K_d) in the CCA calculations.

BRAGFLO 2D/3D Modeling

The results of the DOE 's screening analysis for repository processes (FEP S-1) suggest that the two dimensional BRAGFLO model used in the CCA calculations may be misrepresenting repository performance at pressures above the anhydrite fracture pressure. There is the potential of substantially greater brine saturation in the repository at higher pressures than calculated for the CCA. The discrepancy between the 2D and 3D versions of BRAGFLO may have resulted in an underestimate of radionuclide releases to the surface. To resolve this issue, the EEG recommended that several 3D BRAGFLO simulations of the repository should be performed using the parameter values of vectors used in the CCA performance assessment. The 3D BRAGFLO simulations should be used to provide repository conditions for the normal suite of direct brine release calculations. The calculations should also be assessed in terms of impact on spallings calculations.

The DOE and the EEG held a meeting on February 17, 1998, to try to resolve this issue. It was agreed at that meeting that there was sufficient reason to further investigate the potential for greater brine inflow to the repository using 3D modeling compared to the calculated value using the 2D model of the CCA. It was agreed that a simulation corresponding to a parameter vector that led to high pressure and anhydrite fracturing in the CCA calculations will be sufficient to demonstrate the potentially increased brine inflow in comparison to the CCA calculation.

Brine Reservoirs

The EEG raised a number of issues related to the Castile Formation brine reservoirs in commenting on the CCA. The EPA has accepted all of the EEG suggestions except the one related to the assumption of the probability of encounter of brine reservoirs, and we disagree with the EPA on this issue. The CCA assumed 8% probability on the basis of faulty assumptions. The EEG recommended 100% probability on the basis that the WIPP-12 brine reservoir was large enough to most likely extend under the repository, a conclusion also confirmed by geophysical testing directly above the repository. The EPA has sampled on a range of 1 to 60%, but has provided no basis for assuming less than 60%. Based on the arguments that the geophysical (Time-domain electro-magnetic survey) data may be interpreted to indicate the brine to be under 60% of the repository, and that some boreholes adjacent to the brine producing boreholes are known to be dry, the EEG is willing to accept the assumption of a fixed 60% probability of encounter, and recommends that a new performance assessment calculation be run with this fixed value.

Waste Issues
DOE calculations showed that non-random emplacement of radionuclides in the repository led to significantly higher releases from cuttings and cavings and spallings. EEG believes that releases from Direct Brine Releases will also increase. Revised calculations should be incorporated into the CCDF even though partial sensitivity analyses indicate that non-random emplacement would not, by itself, result in non-compliance.

The expected quantity of cellulosics, rubber, and plastics (CRP) in the repository is slightly greater than the waste repository limit. The ability to characterize CRP waste with sufficient accuracy has not been shown. Also, EEG believes the limit should be controlled on a per panel basis rather than for the entire repository.

Assurance Requirements
There are six assurance requirements in the EPA standards (40 CFR 191) which were incorporated to provide additional confidence in the repository, because of the inherent uncertainty in projecting the future behavior of natural systems and inadvertent human action. The EEG agrees with the EPA determination of two of these six requirements, the active and the passive institutional controls, but has questions about the other four. The monitoring plan does not appear to meet the intent of the standards. DOE's retrieval plan and the EPA's determination of its compliance with the requirement appear to give a false sense of security regarding the retrievability of waste. WIPP does not appear to meet the intent of the resource disincentive requirement, and this is an additional reason for EEG to argue that additional engineered barriers should be incorporated in the WIPP design for making the waste less respirable and soluble through treatment and repackaging. Since DOE has plans to treat or repackage 85% of the existing contact handled TRU waste anyway, this recommendation should be easy to implement.

Individual Protection Requirements
Although EEG has minor disagreements about several assumptions used by DOE in evaluating the Individual Dose Requirements, we agree that compliance with these requirements has been demonstrated.

Environmental Standards for Ground-Water Protection
EEG believes there is a very low probability of significant contamination of an Underground Source of Drinking Water (USDW) by an undisturbed release. However, 40 CFR 191.24 specifies that no contamination is permitted if the USDW is initially at or above the radionuclide limits of 40 CFR 141. No documentation of current radionuclide concentrations in the USDWs has been provided. EPA needs to require submission of data showing the USDWs are below allowed limits or that there is a zero probability of any contamination reaching the USDW.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Project is a planned geologic repository for disposal of transuranic (TRU) waste, generated from the nuclear defense programs of the USA since 1970. The repository is located at a depth of 655 meters in the Permian age salt beds of the Salado Formation in southeastern New Mexico, 40 km east of Carlsbad, NM. Since 1978, the Environmental Evaluation Group (EEG) has evaluated various technical aspects of the WIPP project that relate to the impact on the public health and the environment of New Mexico. A list of published reports appears at the end of this report. The U.S. Department of Energy (DOE) is responsible for the management of defense TRU waste as part of the U.S. defense nuclear complex following its predecessor agencies, the U.S. Atomic Energy Commission (AEC) and the Energy Research and Development Authority (ERDA). Before 1970, such waste was buried in shallow pits at several national laboratories. DOE plans to ship only the post-1970 TRU waste to WIPP, that has been stored in above-ground tension-support structures at the national laboratories.

The TRU waste inventory currently in retrievable storage at the DOE sites totals about 104,000 cubic meters including 27,000 m^3 of alpha emitting low level waste scheduled for processing, or the rough equivalent of half a million 55-gallon drums (U.S. DOE, 1995b). The WIPP has been designed to contain up to 168,500 cubic meters (approximately 810,000 drum-equivalent) of contact-handled (CH-TRU), and up to 7100 cubic meters (7500 canisters) of remote-handled (RH-TRU) waste. The CH-TRU waste may have a maximum surface-dose rate of 200 millirem per hour. Ninety-five percent of the RH-TRU canisters disposed at WIPP may have a surface dose-rate of a maximum of 100 rem per hour, and five percent by volume may have a maximum of 1000 rem per hour. The TRU waste generated in the future will come from dismantling and cleanup of the nuclear weapons complex and may be different than the existing waste.

Excavation of the WIPP repository began in 1982 and all the surface facilities, four shafts, and all the basic underground facilities, including 1/8 of the repository “rooms”, had been excavated by 1988, the year when the DOE had planned to start placing waste in the repository for experiments and operational demonstration. The DOE abandoned this plan in 1993 because there was insufficient justification for conducting the *in situ* experiments with waste and it would have been difficult to ensure retrieval of the waste after several years of emplacement.

The decision to use the WIPP repository for permanent disposal of TRU waste will be made, in large part, on demonstration of the facility's compliance with the long-term disposal standards for TRU waste promulgated by the Environmental Protection Agency (EPA) (U.S. EPA, 1993). These standards require a probabilistic assessment of the integrity of the repository for 10,000 years into the future. Such an assessment requires a detailed knowledge of the geological and hydrological characteristics of the site, physical and chemical characteristics of the waste, formulation of scenarios for breach of the repository and release of radionuclides to the environment, calculation of the probabilities and the amounts of release during the future 10,000 years, and comparison with the releases allowed by the standards. The compliance with the standards is to be judged on the basis of a set of criteria promulgated by the EPA (U.S. EPA, 1996).

EEG has participated in the development of the EPA standards for safe disposal of TRU and High Level Waste (40 CFR 191) beginning in the early 1980's, including reviews of various drafts of the EPA standards, testimony at the EPA Science Advisory Committee Meetings, EPRI workshops, NAS Board on Radioactive Waste Management Workshops, and Congressional Committees. Detailed reviews were provided during the development of the standards, the criteria (40 CFR 194) to implement them, and the Compliance Application Guidance document.

The DOE published a Draft Compliance Certification Application (DCCA) for WIPP in October 1995. The EEG reviewed this document and published detailed comments on it in March 1996 (Neill, et al., 1996). The DOE submitted its Compliance Certification Application (CCA) to the EPA in October 1996 (U.S. DOE, 1996c). The EEG submitted the previously published comments (Neill et al., 1996) on the DCCA to the EPA since the DOE had not provided responses to those and had not indicated how the final application (CCA) had been modified as a result of the EEG comments.

EEG provided additional comments on the specific issues in the CCA as attachments to the EEG letters dated February 7, 1997, and March 14, 1997. Copies of these letters with attachments are included in this report as Appendices 8.1 and 8.2 respectively.

Many meetings were held between the DOE and the EPA to discuss various technical issues both before and after the submission of the CCA in October 1996. The EEG started receiving invitations to these meetings after April 1997.

The EPA issued a Proposed Rule (U.S. EPA, 1997c) in October 1997 proposing to certify that the WIPP meets the EPA standards, and opened a four month period for public comments on the Proposed Rule. At the request of EPA, the EEG staff provided the initial EEG reaction to the EPA decision through technical presentations at a meeting on December 10, 1997, in Albuquerque, and followed with a letter dated December 31, 1997, with attachments. A copy of this letter with the attachments is included in Appendix 8.3. The present report contains the EEG's final comments on the EPA's proposed rule.

This report is organized according to the four "requirements" of the EPA Standards (U.S. EPA, 1993), viz., the containment requirements (40 CFR 191.13), the assurance requirements (40 CFR 191.14), the individual protection requirements (40 CFR 191.15), and the environmental standards for ground-water protection (40 CFR 191 Subpart C). The bulk of the DOE application and the EPA's proposed rule deal with compliance with the containment requirements. The bulk of this report, therefore, also consists of the issues associated with demonstrating compliance with the containment requirements. Rather than providing a critique of the EPA proposed rule chapter by chapter, or page by page, the EEG has adopted the approach of discussing what appear to us to be the most significant issues affecting determination of compliance. The issues relate either to a lack or inadequacy of justification of the conceptual models, parameter values, or computer models, that have been used to compute projected releases of radionuclides to the accessible environment, or insufficient basis for not considering certain scenarios for release. Attempt has been made to describe our concerns as clearly and explicitly as possible with suggestions for ways to resolve the issues.

The Environmental Evaluation Group (EEG) was established by the State of New Mexico in 1978 as an independent scientific group to conduct a scientific evaluation of the WIPP project's impact on the public health and environment of New Mexico. In addition to the reviews of long-term and operational-period safety, EEG has conducted environmental monitoring of air, water and soil at the WIPP site and in the surrounding communities since 1984 to establish a pre-operational environmental baseline against which future suspected contamination episodes may be evaluated. This multi-disciplinary group, with offices in Albuquerque and Carlsbad, is funded totally with federal money by Congressional mandate through the DOE. The EEG continues to influence shaping the project to ensure that the public health and safety of the people of New Mexico is not jeopardized and the environment is not adversely affected. The effect of the EEG's work can be seen, for example, in (1) vastly improved geological and hydrological data base and modeling; (2) relocation of the repository to a more suitable area with respect to long-term integrity; (3) safer operational design and procedures; (4) abandonment of the plans to conduct *in situ* experiments with waste at WIPP; (5) continuation of performance assessment work after the disposal standards were vacated by the court in 1986, thus not losing time when the standards were re-promulgated in 1993; and (6) a much safer and more cost-effective redesigned transport container (TRUPACT-II) for the CH-TRU waste shipment certified by the Nuclear Regulatory Commission.

2.0 CONTAINMENT REQUIREMENTS

2.1 SITE CHARACTERIZATION ISSUES

There are a number of issues concerning the understanding of the geological and hydrological setting and processes at the WIPP site that have been debated since the site characterization at the Los Medanos site began in 1974. Some of these issues, such as the characteristics of the brine reservoirs in the Castile Formation and the probability of their encounter, are directly related to the numerical assessments of compliance and are discussed at length as separate sections in this chapter. Other issues, such as the extent of the effect of Karst processes at the WIPP site and the anomalous water-level rises in a number of boreholes, may have an impact on numerical assessments but the DOE claims that they do not and the EPA has accepted that assertion. There is a third set of site characterization issues which do not appear to have a direct impact on the numerical assessments as framed by the CCA, but relate to the credibility of understanding of the geological and hydrological processes operating at present and how that understanding is used to understand the past evolution and future predictions. In this third category, one may include the issues of recharge and discharge of groundwater, location of water table, the extent and rate of basin-wide dissolution processes, etc. Issues falling in all three categories are discussed in this section. To keep the discussion brief and easy to read, references to previously published reports and papers are frequently made, and only summary statements are provided here.

Chaturvedi (1993) provides the most up to date summary of the EEG's evaluation of these issues, and this paper is included in this report as Appendix 8.5. These issues are discussed by the EPA in the Technical Support Document for Section 194.14 (U.S. EPA, 1997g), CARD 14 (U.S. EPA, 1997b), and the proposed rule itself as published in the Federal Register on October 30, 1997 (U.S. EPA, 1997c).

2.1.1 History of Site Characterization Efforts

Before discussing the specific issues, a brief history of the site characterization efforts for WIPP may be helpful in putting these issues in perspective. Following the abandonment of the Lyons, Kansas site in 1972, a 3.2 km by 2.4 km (2 mile by 1.5 mile) site was selected by the Oak Ridge National Laboratory on behalf of the then Atomic Energy Commission, 11 km northeast of the present 6.4 km by 6.4 km (4 mile by 4 mile) WIPP site. Cores from two boreholes (AEC-7 and AEC-8, Fig. 1) penetrating through the Salado Formation drilled at the northeast and the southwest corners of that site indicated acceptable geology. Sandia National Laboratories (SNL) was given the responsibility for site characterization of WIPP in 1975. A third borehole (ERDA-6; see Fig. 1) drilled by SNL at that site in 1975 encountered a pressurized brine reservoir and intense structural disturbance in the fractured upper anhydrite of the Castile Formation at a depth of 826 m (2709 ft). As a result, the location of the repository was moved to the present site.

The DOE had declared the WIPP site to have been adequately characterized in 1981 on the basis of the Geological Characterization Report (Powers, et al., 1978) and the Environmental Impact Statement (U.S. DOE, 1980). The EEG recommended additional field and laboratory studies to resolve several geological and hydrological questions based on the consensus reached at a scientific conference organized by the EEG in January 1980 and a 3 day field conference at the site in June 1980 (Chaturvedi, 1980). These recommendations were included in a stipulated agreement between the DOE and the State of New Mexico signed in 1981 as part of the settlement of a lawsuit filed by the State Attorney General. One of the EEG recommendations was to deepen the borehole WIPP-12 which had been drilled through the Salado Formation in 1978 to a total depth of 845.6 meters (2773.6 ft), only 14.7 meters (48.3 ft) below the Salado/Castile boundary in to the Castile Formation, but was completed only to the base of the Salado at 834.5 meters (2737.5 ft). Two (N-S and E-W) seismic reflection profiles crossing at the WIPP-12 indicated anticlinal structure at the depth of the Castile Formation at this location, and the EEG suspected the presence of a Castile brine reservoir at this site. The borehole was deepened from its 845.6 meters (2773.6 ft) depth to a total depth of 1197.4 meters (3927.5 ft) in November-December 1981. Pressurized brine associated with hydrogen sulfide gas was encountered at 919.5 meters (93016 ft), only 74 meters (242.4 ft) below the original depth of the borehole. The EEG recommended relocation of the repository, because according to the plans at that time, the repository was in the northern part of the underground area to be excavated and the edge of the repository would have been only 170 meters (558 ft) south of WIPP-12. The DOE agreed to rotate the repository design so that the experimental area is now located north of the center of the site, and the repository to the south.

The DOE presented the results of the additional studies to the EEG during 1982 and 1983 (EEG, 1983). The EEG published its evaluation of the suitability of the WIPP site in 1983 (Neill et al., 1983) and expressed confidence in the site but also concluded that additional work was needed for assessing compliance with the long-term standards that were in the process of being developed

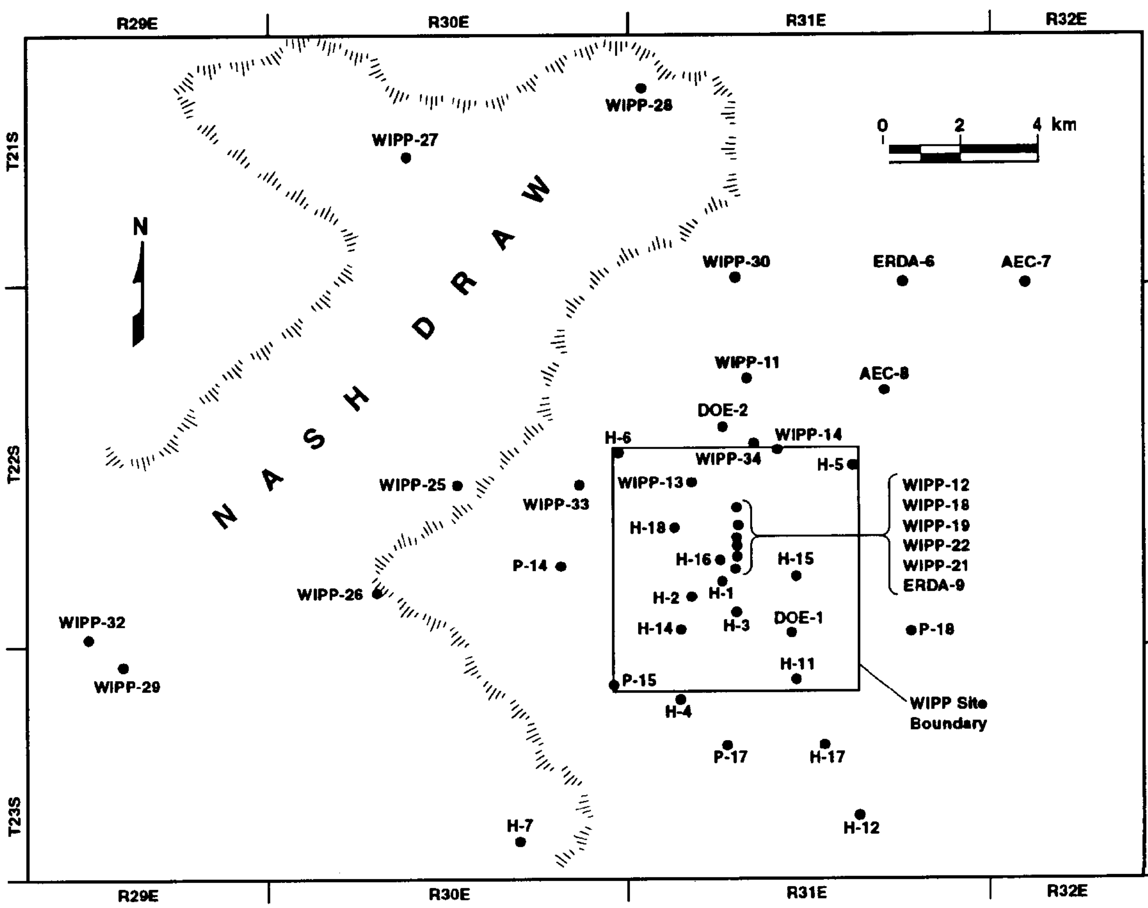

Fig. 1. Location of WIPP Boreholes

by EPA at that time. These additional recommendations related to (a) identifying the extent of the underground brine reservoir in the Castile Formation that had been encountered by the borehole WIPP-12, (b) to address and try to resolve controversial geological issues such as deep dissolution in the Salado Formation and the formation and occurrence of breccia pipes, and (c) to better define the hydrological and radionuclide transport characteristics of the Rustler Formation with its two aquifers. Field and analytical studies conducted since 1983 have answered many of the questions and brought others closer to resolution. Additional specific questions developed as the performance assessment process started in 1986. The EEG has continuously been involved in attempting to resolve these questions.

2.1.2 Deep Dissolution

The EEG agrees with the EPA's conclusion that deep dissolution of the Salado Formation salt is not likely to be a threat to the WIPP repository. A history of the efforts made by the EEG, Sandia National Laboratories, and the DOE to resolve this issue is found under the heading "Dissolution of Salado Salt" in Chaturvedi (1993), Appendix 8.5 of this report.

2.1.3 Karst Processes at the WIPP Site

The WIPP site is located in a karst region and the topography to the west and south of the site is developed in response to the karst processes. However, no sinkholes have been identified at the WIPP site proper and extensive hydrological testing, including several multi-well flow tests at the site, have not encountered karst channels of significantly anomalous transmissivity. Multi-well flow tests have, however, given indications of north-south trending preferential flow paths in the northwestern and the southwestern parts of the WIPP site. The well WIPP-30 (Fig. 1) is located 5.6 km (3.5 miles) NNE of the well WIPP-13, but showed a significant drawdown starting only a few hours after pumping at WIPP-13 began (Beauheim, 1987). This observed drawdown in response to pumping WIPP-13 was higher than at several boreholes closer to WIPP-13, indicating a NNE trending high transmissivity connection between WIPP-13 and WIPP-30. Similarly, the rapid and high magnitude responses observed in wells DOE-1, H-3, and H-15, as a result of pumping in H-11 (Beauheim, 1989) are believed to reflect the presence of a fracture network extending to the north and northwest from

H-11 (see Fig. 1). While these high transmissivity zones are taken into account in the modeling of flow through the Rustler, there are remaining questions that have been raised by Leonard Konikow of the NAS WIPP Committee, and David Snow, regarding the nature of flow and transport through the Culebra, particular in the region directly above the repository, that have not been satisfactorily addressed in the proposed rule.

In summary, with respect to the karst question, while the EEG agrees that karst channels and sinkholes have not been found in the WIPP area east of the sink hole in which WIPP-33 (see Fig. 1) was drilled, we are less certain than the EPA about rejecting the possible effects of this phenomenon now and in the future. The EPA has concluded, "karst is not a problem at WIPP and that geologic evidence of the last approximately 500,000 years and results from DOE's groundwater modeling indicate that future development of karst at the WIPP is not likely." (U.S. EPA, 1997c, p. 58799). The EEG view is that while the effects of karst processes have not been identified at the WIPP site proper, the site is located in a karst region. Therefore, in considering the flow and transport through the Culebra, allowance should be made of this fact and the conceptual models, parameter values, and numerical modeling should be conducted with relatively conservative assumptions. A discussion of the issues of flow and transport through the Culebra is presented in Section 2.9 of this report.

2.1.4 Dewey Lake Redbeds Hydrology

The hydrology of the Dewey Lake Redbeds (DLR) and the overlying Santa Rosa Formation has not been adequately considered in the CCA. The CCA rejected consideration of transport through the DLR on the basis of the DOE assumption that "chemical retardation occurring in the Dewey Lake will prevent release within 10,000 years of any actinides that might enter it." (U.S. DOE, 1996c, p. 6-149). This decision is based on an analysis conducted by Wallace et al. (1995), who assumed the K_d values for the DLR for different radionuclides on the basis of "literature search for sand/sandy soil in saline waters". No K_d values have been obtained on the DLR rock, in situ or in the laboratory, and the reported values from the literature search are meaningless because they were conducted on a variety of soils under a variety of conditions unrelated to the DLR Formation. This fact is obvious from the extremely wide range of reported values; e.g., Table NS1-A3 of Wallace et al. (1995)

reports K_d of 100 to 100,000 mL/g for Plutonium. The EEG therefore rejects the CCA assertion about the contaminant transport through the DLR.

The EPA has advanced an additional argument for not considering DLR as a transport pathway. The proposed rule (U.S. EPA, 1997c, p. 58799) states: “the CCA PA results indicated that no contaminated brine traveled up an intrusion borehole past the Culebra to the Dewey Lake or other units.” It is common knowledge that the postulated rise of contaminated brine up an intrusion borehole is based on the assumptions made in conducting the performance assessment rather than any specific inherent property of the system. This EPA assertion for not considering contaminant transport through the DLR is therefore also without basis.

The DOE has conducted hydrological tests in the Dewey Lake Redbeds and the Santa Rosa Formation in 1997 after the submission of the CCA to investigate the source of water leaking in the WIPP exhaust shaft. These tests, conducted at the center part of the site overlying the repository, show that water in the lower Santa Rosa/Upper Dewey Lake Formations is more prolific than believed before (Duke Engineering Services, 1997). The results of these tests and the surprising encounter of water in the DLR in the borehole WQSP 6 and 6a at the site indicates that more surprises may be in store with respect to the hydrology of this Formation. The WQSP 6a produced 12 gallons per minute water of relatively good quality (4,000 mg/L). The EEG recommends a thorough re-examination of the Dewy Lake Redbeds issue.

The NAS WIPP Committee (NRC, 1996) concurs with the EEG view on this issue:

> In the Committee’s opinion, releases to the Dewey Lake cannot be discounted summarily; if a borehole to the Salado or to the Castile Formation were to connect these formations to brine at a pressure near lithostatic, then the hydraulic gradient (driving Darcy flow) would be sufficient to enable leakage into both the Culebra and the Dewey Lake if a pathway to either formation were to exist. (NRC, 1996, p. 74).

The NEA/IAEA International Review Group (NEA/IAEA, 1997) also expressed a similar opinion on this subject:

> The IRG considers that, from a dose perspective, greater attention could be given to considering whether any credible scenarios exist in which contaminants might reach these potable or nearly potable resources, under present day and alternative climate conditions.

2.1.5 Rustler Formation Geology and Hydrology

The EEG continues to disagree with several aspects of the CCA conceptualization of the past history of the Rustler Formation, that EPA has accepted without sufficient critical examination of the evidence for alternative conceptual models. These issues are briefly discussed below with references to the EEG reports and papers where more details can be found.

2.1.5.1 Pattern of Rustler Salt

The EEG has shown (Chaturvedi and Channell, 1985; Lowenstein, 1987) that the pattern of occurrence of salt in the Rustler Formation can be more rationally explained by the hypothesis of post-dissolution salt removal as first proposed by Snyder (1985), rather than the Holt and Powers (1988) and Powers and Holt (1990) hypothesis of original deposition. Based on a detailed sedimentological study of the Culebra cores from a number of wells at the WIPP site, Lowenstein (1987) interpreted four distinct dissolution zones in the Rustler Formation.

2.1.5.2 Origin of Rustler Fracturing

The pattern of fracture distribution and corresponding transmissivity values distribution in the Culebra is too complex to be explained away in a simple statement like "density of open fractures in the Culebra decreases to the east", and as expected, has become more complex with additional data acquisition.

The respective thicknesses of the Rustler and the upper Salado (Chaturvedi and Channell, 1985, Fig. 8, p. 23) call into question the Beauheim and Holt (1990) proposition that dissolution of the upper portion of the Salado Formation may have caused subsidence and fracturing in the Culebra. The Rustler Formation is 137 meters (450 ft) thick four miles east of the center of the WIPP site and only 90 meters (300 ft) thick from the center of the site westward. The upper Salado (from the top of the Salado to Marker Bed 103), on the other hand, maintains a uniform thickness of about 58 meters (190 ft) over the WIPP site and only decreases in thickness west of the Salado dissolution front that coincides with the western margin of the WIPP site. It would be more logical to postulate the gradational removal of salt from the Rustler Formation itself to have caused fracturing in the Culebra over the WIPP site. West of the Salado dissolution front (west of the WIPP site), both the Salado and the Rustler have been affected, grading into total collapse in the Nash Draw.

If the high transmissivity zone in the southeastern part of the WIPP site is related to the dissolution of gypsum fillings in the Culebra fractures, then the high transmissivity zone may extend to the south-central part of the WIPP site.

2.1.5.3 Age of Rustler Water

The EEG has never accepted the bases for the assumption of the Rustler water being “fossil” water, having been recharged under climatic conditions significantly different from the present. Since the EPA has accepted this hypothesis as postulated by the DOE, it is important to state the reasons in detail for the EEG believing that the Rustler water is a mixture of “old” and “new” water, including modern day meteoric recharge.

2.1.5.3.1 Hydrogen and Oxygen Isotopes in Groundwater

The EEG (Chapman, 1986) compiled stable isotope data from throughout southeastern New Mexico and compared them to data from the WIPP area. The stable isotopic compositions of most samples of groundwater from the Rustler Formation were found to be similar to the composition of other, verifiably young, groundwater in the area. Though the stable isotope data cannot indicate ages for water in the various aquifers, neither did the data show any distinction between most Rustler groundwater and verifiably young groundwater. A small number of samples, primarily from the Rustler/Salado contact east of Nash Draw, had isotopic compositions that are not characteristic of recently recharged meteoric water. These waters' enrichment in heavy isotopes may be due to mixing with deeper groundwater (supported by the stable isotopic composition of Salado fluid inclusions and Castile brine) or to exchange between the groundwater and hydrous minerals.

A comparison of the heavy isotope enrichment observed in evaporating waters and the composition of the water at WIPP-29 and the Surprise Spring showed that the isotopic composition of these Nash Draw waters could be derived by evaporating Rustler groundwater. Based on stable isotopes, both WIPP-29 and Surprise Spring could be discharge areas for Rustler groundwater moving from elsewhere in Nash Draw and the east.

The enrichment in heavy isotopes found in the water from pools in the Carlsbad Caverns was used by Lambert (1987b) as evidence that the relatively depleted Rustler water was recharged during a past, more pluvial, time. However, the uniqueness of the isotopic composition of water in the Caverns' pools suggests that rather than representing the composition of recent recharge, the heavy isotopes are enriched by evaporation and equilibrium isotope exchange in the humid cave environment. Recharge in the extreme karst environment near the cavern may also favor isotopically heavy precipitation. Therefore, the EEG suspects the interpretations from the Lambert (1987b) study regarding the age of Rustler water.

2.1.5.3.2 Radiocarbon Ages of Groundwater

The radiogenic age statement in section 2.2.1.4.1.2 of the CCA is based on Lambert (1987a). This report was reviewed for EEG by Dr. Fred Phillips of the New Mexico Institute of Mining and Technology in 1987 who found the conclusions of the report to be unacceptable for reasons described below.

While it is true that all of the samples (excluding H-5C, which may possibly be contaminated) are probably in the age range 10,000 to 16,500 years B.P., the ages of the water samples vary in a systematic fashion from youngest (10,000 years) in the north to oldest (16,500 years) in the south (with the exception of H-5, which is clearly on a different flow path than the other ^{14}C sampling wells). This corresponds to the pattern expected from the north-to-south flow direction inferred from the physical hydrology. Thus a more reasonable interpretation of the ^{14}C age distribution is that only a segment has been sampled in the middle of a large-scale flow system. Additional ^{14}C samples to the north and/or east might well yield Holocene ^{14}C ages. Also, well H-5, although it may be contaminated, may also indicate active recharge.

The major conclusion of the report (Lambert, 1987a, p. 5-10 and 81) was, "Because of the questionable validity of the assumptions necessary in applying radiocarbon and radiochlorine dating methods in the evaporite environment of southeastern New Mexico, and because of the previously demonstrated susceptibility of these components to contamination in this groundwater system, these methods will not be pursued beyond this feasibility study." The EEG finds this conclusion to be unnecessary because good results have been obtained from uncontaminated wells. Ground-water systems are fundamentally not amenable to intensive sampling and thus in all ground-water investigations (whether physical or geochemical) assumptions regarding the system are necessary. Useful results can be obtained, even given a wide range in parameters assumed for the ^{14}C dating model. With a properly conducted field study of the system, the parameters could undoubtedly be constrained much more closely and much better refined dates obtained. Because interpreting WIPP site flow patterns by physical hydrology alone is very difficult and uncertain, and because ^{14}C tracing may hold the best hope of elucidating the flow system, the very negative viewpoint expressed by Lambert (1987a) is considered by the EEG to be totally unwarranted.

The contamination issue is even more clear cut. Certainly, it is true that a majority of the wells sampled during this study did not yield useful results due to contamination. One does not need to be an expert in ^{14}C to predict that wells crammed with "shredded paper, cottonseed hulls, peanut shells, and various proprietary organic additives" (Lambert, 1987a, Section 4.2.6) will not yield meaningful ^{14}C dates. There is very little logic in arguing that because wells deliberately injected with organic material were contaminated, all other wells must also be. Contrary to the statement by Lambert (1987a, p. 23), contamination during drilling is not "inescapable". The best evidence of this is that four of the wells drilled without organic circulation-loss additives did not show any sign of contamination. There is no evidence that this groundwater system is unusually "susceptible" to contamination. Any system is susceptible to inappropriate drilling practices, and appropriate practices should yield acceptable results at the WIPP site.

Based on the data contained in Lambert (1987a), the EEG came to a different conclusion. In all cases, where ^{14}C could reasonably be expected to give useful results, it did so. Although there were only a limited number of uncontaminated samples, the geographic distribution of the resultant ages is hydrogeologically reasonable. The EEG advised the DOE not to abandon this potentially very informative avenue of investigation in 1987 and the EEG recommendation was incorporated in the 1988 modification to the DOE/State of New Mexico Consultation and Cooperation Agreement. However, the DOE did not pursue this investigation.

2.1.5.3.3 Uranium-Isotope Disequilibrium Data

The Lambert and Carter (1987) report was reviewed for the EEG by Dr. John Osmond in 1987. Dr. Osmond is the co-inventor of the Uranium-isotope Disequilibrium technique applied to the study of groundwater flow. Based on Dr. Osmond's review, the EEG provided comments on the Lambert and Carter (1987) report to the DOE through a letter dated 12/2/1987. The following is a summary of those comments.

The limitations of the application of uranium systematics to groundwater interpretations should be kept in mind:

1) one usually cannot deduce from the uranium data alone the **direction** of groundwater flow,
2) one usually cannot determine the **flow rate** of groundwater itself by the use of U-234 decay rates.

The same isotopic data can be used to model water flow in more than one direction. This is because changes in isotopic ratio can be caused either by true ageing (decay or growth of U-234) or by water-rock or water-water interactions. Researchers in this field usually have independently derived information as to flow directions, which they can use to deduce the possibility of uranium leaching or the mixing of two or more groundwater sources.

Investigators can sometimes determine, in deep confined aquifers, the rate of movement of uranium in the system. The rate of flow of the water itself, however, must be inferred from one's estimate of the retardation factor for uranium in that particular aquifer.

That an aquifer is "confined" is usually an assumption of the modeling of slow-moving systems. Mixing with undefined waters, whether from recharge or other aquifers, negates any evolutionary conclusions. The authors of this report recognize the potential problem, but argue against leakage, perhaps too readily.

Finally, when uranium leaching or adsorption is inferred, it should be remembered that only the grain or fracture surfaces of the host rock are involved. The concentration of uranium on these surfaces can be much different than the concentration values of the whole rock.

Therefore, the principal conclusions of the report must be regarded as possibly overstated: 1) it is possible, but not proven, that the Rustler system can be modelled as a confined aquifer, 2) it is plausible that the flow regime has changed direction, but alternative interpretations based on a more steady-state model are readily visualized, and 3) although the inferred rate of movement of uranium through the aquifer near the site is probably about right, the flow rate of the water itself could be appreciably faster.

The basic pattern of occurrence of uranium isotopes in the Rustler ground water in the western half of the study area, as pointed out by the authors, is consistent with a two-source mixing model. These two end members could be water masses represented by H4 and W29, or by a water with very little U-238, but considerable excess U-234, that has leached to varying degrees uranium from the aquifer rock. The regression line on Fig. 15 implies that these two end members are leached uranium (infinite concentration) with an atomic ratio of 1.55 and water of zero concentration of U-238 but carrying 13.4 ppb (U-238 equivalent) of U-234.

The authors make use of this pattern to make three different interpretations. Each interpretation is plausible to some degree, but taken together they are somewhat inconsistent.

The most logical has to do with a possible westward flow direction of water from the site toward Nash Draw. Low concentration water (with respect to U) gradually dissolves uranium with lower atomic ratio values. No information regarding flow rate derives from this model.

The least plausible interpretation assumes that the decrease in atomic ratio westward is the result of U-234 decay, which leads to deductions regarding low U movement rates (not necessarily low water flow rates). It is recognized by the investigators that such a model is suspect where uranium concentration values are increasing; leaching, if ignored, produces inferred flow rates which are too low.

The third interpretation is inconsistent with the first, so the authors postulate an earlier flow regime and ask as to why the atomic ratios are so high to the East. Such values depend on fractionation processes that often require time periods commensurate with the half-life of U-234, and therefore are nearly always down-flow. In this case, argue the investigators, the estimates of time are apt to be conservative because leaching would hold the atomic ratio values down.

In all of their modeling, the authors of this report display considerable knowledge and insight; they do not flagrantly misinterpret the data. Their assumptions are made clear. Nevertheless, one aspect of uranium isotope systematics in groundwater is neglected, and could affect their models. In any ancient system, uranium has been moving for much longer than the period of time being modeled. The distribution factor between dissolved and adsorbed uranium (related to retardation) means that any interactions between water and rock are probably independent of whole-rock uranium concentration values. It is the concentration of uranium on adsorption surfaces, rather than that inside the rock particles, which determines how much fractionation occurs, and how fast relative to water movement. The concept of "reducing barrier" is often cited to explain concomitant decreases in U concentration and increases in atomic ratio over short distances.

The potentiometric contours of the Culebra suggest two flow lines in the study area: to the west, flow is more or less directly south; in the general area of the site, however, there appears to be an easterly flow in the north, a southeasterly flow at the site, and a southerly and westerly flow to the South.

If we postulate a general source area anywhere to the North, with the usual reducing barrier not far from the point of recharge, then all of the water would enter the area with a high atomic ratio and a low concentration. Water flowing southward in the west would dissolve uranium and take on the higher U and lower atomic ratio fingerprint. Water flowing in the east would move slower, dissolve less uranium, and have its atomic ratio altered only gradually with time. When the flow looped west, dissolving and "mixing" with rock-derived uranium would occur.

This scenario combines the three models proposed by Lambert and Carter (1987): mixing in the west and southwest, increasing atomic ratio due to recoil-type fractionation in the north, and decay of excess U-234 in the general area of the site. If this model has merit, we can deduce uranium movement rates in the aquifer near the site which are consistent with those values proposed by the investigators. Because of the retardation factor, the water flow rate could be higher.

All of these remarks concern the Culebra unit of the Rustler. There are not enough data from the other units to do any regional modeling. However, the fact that none of the atomic ratio values from above and below are as high as some from the Culebra suggests that the latter is the "tightest" with respect to uranium mobility.

Apparently the data regarding oxidation potential of the Culebra waters is inconclusive; and the same might be said about the other hydrologic and geochemical information that might be used to demonstrate that the Culebra is truly confined. Uranium isotopic data has often been used as evidence in such interpretations. Most deep confined aquifer waters carry uranium at very low concentration levels, on the order of .1 to .001 ppb., and with quite high atomic ratio values, anywhere from 2 to 20 or more. The Culebra waters have higher uranium concentration than do truly reducing aquifers suggesting the possibility of leakage from shallower horizons. However, the fact that the isotopic data can be used to model flow in systematic ways suggests that such invasions are not the predominant process. Any such oxidative tendencies would favor interactive models (uranium leaching) over the fractionation and time-related models emphasized by Lambert and Carter (1987).

Regarding flow rates and groundwater residence time, Lambert and Carter (1987) consistently confuse *uranium* residence time with *groundwater* residence time. The data presented in the report do not allow for the calculation of groundwater ages. Even when the appropriate retardation factors and grain and fracture surface characteristics are known, there are still serious questions about applying uranium isotopic data to determine basic groundwater flow characteristics. Davis and Murphy (1987), Simpson et al (1985), and Hussain and Krishnaswami (1980) all express serious reservations about the reliability of uranium-disequilibrium dating because of the many difficult-to-substantiate assumptions involved.

The amount and reliability of the data are also questionable. Outside of Nash Draw, the authors have only four wells on which to base conclusions of changes in flow direction. It is important to consider the dual-porosity nature of the Culebra, indicated by the recent hydrologic testing. The very high activity ratios at H-4 and H-5 may be related to the low-transmissivity, matrix flow found at those wells. Conversely, the lower activity ratios at H-6 may be the result of rapid groundwater flow through fractures. More data east of Livingston Ridge, and from fracture-flow areas such as near H-11 and DOE-1 must be collected before any confidence can be placed in conclusions about flow paths.

Considering the serious questions of groundwater contamination in Nash Draw raised by Lambert

(1987a), there should be an in-depth discussion of the reliability of the presented analyses of a trace constituent like uranium. If contamination with organics is as pervasive in the Nash Draw wells as reported in SAND86-1054, this would very likely alter redox conditions near the wells. Oxidation-reduction potential is an important control on uranium content. Though the authors state on page 6 that the uranium values and isotope ratios have been perturbed at W-29 by wastewater dumping, they then proceed to use this value throughout the report, for instance as an important part of their argument for recharge in southwest Nash Draw.

As previously mentioned, redox conditions are an important factor in modeling uranium behavior. Field evidence (Eh values as reported in Uhland and Randall, 1986 and Uhland et al, 1987) and the relatively high uranium values both argue against reducing conditions in the Culebra. There is no evidence for the "reducing barrier" required by Lambert and Carter's model. The authors should provide some discussion of the physical requirements of the model relative to known aquifer characteristics.

The section on "Implications" for recharge, karst flow, and climate change presents insufficient discussion for reaching the presented conclusions on this broad topic. For instance, if no recharge is supposed to be occurring, there should be some discussion of what happens to rainfall. There is no integrated surface drainage, there are numerous gaps in the Mescalero caliche, and 20 inches of annual rainfall has been common the last few years. The role of southwestern Nash Draw (SWND) is another point requiring additional discussion. The authors present contradictory hypotheses in this section. Lambert and Carter's item number 2 on page 45 says SWND is a recharge area, while item number 4 on page 46 calls for discharge in that area.

Contradictory statements are also made regarding the degree of vertical interconnection in Nash Draw. Item 5 on pages 46 and 47 (Lambert and Carter, 1987) argues that the Magenta and Culebra are freely connected at W-25 and W-27 (as previously discussed in Chaturvedi and Channell, 1985, though overlooked in Lambert and Carter's references). However, item 4 on page 46 argues that recharge to sinkholes in the Tamarisk member cannot be interpreted as providing recharge to the

Magenta or Culebra. Are the authors proposing that the Magenta and Culebra are well-interconnected, but not the intervening Tamarisk? Some discussion of this extraordinary hypothesis is warranted. Likewise, more discussion must also be provided of the author's assertion that the dominant process at W-33 is alluvial infilling. The continued presence of this large depression, even after the springs have ceased to flow, argues against infilling at the surface. We are not aware of any evidence or studies that support the author's statement.

In light of the above comments on the Lambert and Carter (1987) report, all the assumptions arising from the conclusions of that report should be reexamined.

2.1.5.4 Effect of Clays in the Culebra

While the CCA does not assume clay lining in the fractures of the Culebra, the concept of the existence of clays, specifically the clay mineral Corrensite in the Culebra is mentioned in several documents of the proposed rule. Some discussions of this issue refer to the decision to not assume the fracture linings coated with Corrensite to be a conservative decision. It is therefore important to demonstrate that the presence of Corrensite in the Culebra fractures is only a myth without any basis in fact, as described below.

The Corrensite hypothesis is based on the X-Ray Diffraction and Analytical Electron Microscopy analysis of samples collected primarily from clay rich layers of the Rustler Formation from cores of wells drilled primarily in the Nash Draw. Four reports are cited to support this conclusion. These reports are based on the work of Terry Sewards and others at the University of New Mexico under contract to the Sandia National Laboratories.

Sewards, et al. (1991a) contains mineralogical analysis of core samples from a single well, WIPP-19, and presents no claim for clay filled fracture linings in the Culebra.

Sewards (1991) presents data on the "whole rock" as well as the "fracture surface" compositions of samples of cores collected from 6 wells (WIPP-26, 27, 28, 29, 30, 32) in the Nash Draw, one borehole (WIPP-33) between the Nash Draw and the WIPP site, and three boreholes (WIPP-12, 13, and 34) in the northern part of the WIPP site. Clays are expected to be present in the Nash Draw cores because of extensive dissolution, weathering, and erosion in that area. WIPP-33 is located in a sink hole and processes similar to Nash Draw have operated there as well. Boreholes 12, 13 and 34 are located north of the WIPP repository and upstream from the direction of flow of water in the Culebra. Furthermore, the cores from these wells were selected from known clay seams. For example, the only sample from WIPP-12 (CS-1) came from the zone 838.5 to 838.7 ft below the surface. The Basic Data Report for WIPP-12 (Sandia, 1982) identifies mud seams at 837.7 and 840.7 ft depths.

Three Sandia National Laboratory scientists (Sandia, 1992, pp. A-127 to A- 131) correctly evaluated the Sewards (1991) report and stated the following:

> "Sewards (1991) measured and reported clay abundance for eighteen Culebra samples; thirteen from locations to the north and/or west of the WIPP site, and five from the north end of the WIPP site. None of these samples was from wells along fast transport paths. Because Sewards (1991) was focusing on clay abundance and compositional analyses, it is likely that samples were selected for analysis based on visual appearance of clays. Thus, these data may not be representative of clay abundance on fracture surfaces in the area of interest for transport modeling." (Sandia, 1992, Memo from Craig F. Novak, et al. to Martin S. Tierney, p. A-127 to A-131).

Having made this statement, it is surprising that the authors of the memo, Messrs. Craig F. Novak, Fred Gelbard and Hans Papenguth, nevertheless recommended assuming the probability of the existence of relative thickness of clay linings in the Culebra fractures to be as high as 0.5.

Sewards et al. (1991b) presents mineralogy of 107 samples collected from the cores of 8 wells, 3 of which are located within the WIPP site. However, clay fraction separates (<2 microns) were obtained for only three samples: "WIPP-12 #3, a clay-poor dolomite; WIPP-12 #16, a clay-rich dolomite; and H6B #3, a shale." X-Ray Diffraction analysis was performed on the clay fractions from these three samples, and one sample (H6B #3) was analyzed under the electron microscope. The electron microscopy on this one sample casts doubt on the accuracy of the X-Ray Diffraction technique used:

> "There is, however, a discrepancy between the results of the quantitative XRD analysis and the results of the AEM investigation of sample H6B #3. In that sample, the XRD results show that the sample contains approximately 50% corrensite. When imaging was attempted on the AEM, it was extremely difficult to find any corrensite at all; the dominant phases appeared to be serpentine, illite, and chlorite." (Sewards et al., 1991b, p. VII-19).

The conclusion of this report, quoted below, clearly demonstrates how very limited information has been used to make important interpretations:

> "The fact that corrensite is the dominant phase in the Culebra samples is important. Corrensite has a high CEC and high surface area, thus it is able to sorb radionuclides very efficiently in the event of a low pressure breach in the WIPP facility. Although the clay minerals of only three samples were investigated, the results of Sewards et al., 1991 show that mixed-layer chlorite/smectite is the dominant clay phase throughout the Rustler Formation, so it is reasonable to suggest that the same is true in the Culebra unit." (Sewards et al., 1991b, p. VII-19).

Sewards et al. (1991) mentioned in the above quotation, is Sewards et al. (1991a) of this review, i.e., "Mineralogy of the Rustler Formation in the WIPP-19 core". As stated earlier, that report makes no claim for clays lining the Culebra fractures. Corrensite is only interpreted to be present in some of the samples, as one mineral among many, when powdered bulk samples were analyzed through X-Ray Diffraction. How can this observation lead to the statement cited above?

The final report by Sewards (Sewards et al., 1992), presents mineralogical analysis from 47 samples. Of these, 17 samples were taken from the Culebra, and of these only 9 are from the WIPP site - 6 from the Air Intake Shaft and 3 from WIPP-12. The report states the following with respect to the existence of clay in the fractures of the Culebra Samples:

> "Only small amounts of clay can be sampled from the Culebra fracture coatings; therefore, initial technique and model development for adsorption studies on WIPP clays (Park et al., in review) were carried out with material from a black shale layer in the unnamed member. This material, so-called CorWIPP, is 94% corrensite and is described as Sample AIS-15 in this report. Corrensite has a high cation exchange capacity and affinity for the uranyl ion in dilute solution (Park et al., in review) and could provide significant radionuclide retardation in fractures in the Culebra." (Sewards et al., 1992).

The above quotation clearly identifies the problem with using Terry Sewards' work to conclude that corrensite clay lined fractures in the Culebra may provide retardation for radionuclide migration through the Culebra. The argument is based on a sample from a "black shale layer" obtained from the lower part of the Rustler Formation, below the Culebra, because not much clay could be sampled from the Culebra fracture coatings! And yet, this information is used to argue that "significant radionuclide retardation in fractures in the Culebra" could be present.

Any reference to the existence of corrensite or other clay minerals lining the fractures in the Culebra Dolomite member of the Rustler Formation at the WIPP site should be deleted from the project documents because there is no basis for this assumption.

2.1.5.5 Culebra Geochemical Facies

The EEG has raised the issue of the inconsistency between the inferred direction of flow in the Culebra aquifer and the chemistry of water since the early 1980s and has published three reports on the subject. The issue was first raised by the EEG in 1983 as follows:

> "The unexplained decrease in TDS and a change in the general chemical nature of the Culebra water from sodium and chloride at the site to magnesium, calcium, and sulfate south of the site indicates that insufficient data are presently available to adequately characterize the flow system south of the site." (Neill, et al., 1983, p. 79).

Ramey (1985, Fig. 7) elaborated on this issue and presented the concept of geochemical zonation of the Culebra water. Chapman (1988) further explored the problem and provided a hypothesis to account for the decreasing total dissolved solids in the direction of flow, as follows:

> "As groundwater moves from north to south across the area, the Total Dissolved Solids (TDS) decrease by an order of magnitude and the major hydrochemical facies change from Na-Cl to $Ca\text{-}SO_4$. The only plausible mechanism to effect this change is the influx of a large quantity of low TDS water. The possibility of recharge in the southern area is enhanced by the presence of solution and fill features such as the gypsum caves in the Forty-Niner Member of the Rustler near the Gnome site. These features could behave as conduits supplying fresher water to deeper Rustler units." (Chapman, 1988, p. iv).

The Siegel et al. (1991) report was prepared following a suggestion by the EEG which was incorporated as a requirement of the DOE/State of New Mexico Agreement for Consultation and Cooperation.

The EPA proposed rule mentions this issue (U.S. EPA, 1997c, p. 58799; U.S. EPA 1997b, CARD 14-28; and U.S. EPA, 1997f; U.S. EPA, 1997g, p. 82), but simply cites the additional information provided by the DOE (Docket Item II-I-31) and the conclusion that “it was sufficient to explain Culebra geochemical facies within the WIPP area” (CARD 14-28). No discussion of the new hypothesis and the EPA conclusion is provided. There is also no discussion of how the new conceptual model may effect any assumptions made in the containment requirement compliance calculations.

2.1.5.6 Rustler/Salado Contact Hydrology

The EPA has accepted the CCA contention that the Rustler/Salado contact groundwater zone does not underlie the WIPP site (U.S. EPA, 1997b, CARD 14-21; U.S. EPA, 1997g, pp. 87-88). As pointed out by Chaturvedi and Channell (1985) and Neill et al. (1996, p. 2-3), this assumption is not correct. Most of the WIPP boreholes have found brine in the Rustler/Salado contact zone (see Mercer and Orr, 1979; pp. 10, 46, 63, 77, 98, 104, and 113) within the WIPP site. In fact, according to Mercer and Orr (1979, p. 120), in at least one borehole (P-18), the water-level recovery rate after pumping from this aquifer was much faster than the Culebra recovery rate.

2.1.5.7 Culebra Water Level Rises

Anomalous rise in water levels has been noted in a number of bore holes completed in the Culebra aquifer at and around the WIPP site. No satisfactory explanation has been provided for this phenomenon. This issue is briefly mentioned by the EPA (CARD14-21 and 14-78 and TSD III-B-3, p. 78 and 82), but has been dismissed from further consideration by the following statement:

> Although some water level changes are not yet explained, EPA believes that these are accounted for in the head uncertainty captured by the PA (CARD 14-78).

The TSD III-B-3, page 82 has a similar statement without further explanation. The EEG has examined the validity of this statement and found it to be incorrect. Additional discussion of this issue can be found in Section 2.6.7 of this report.

See Section 2.9 of this report for response to the proposed rule discussion of the lack of contribution to total releases from the ground-water pathway (U.S. EPA, 1997c, p. 58799).

2.1.6 Brine Reservoirs

See Section 2.11 for a discussion of the Castile brine reservoirs parameters used in the CCA and PAVT.

2.2 SUMMARY OF PA SENSITIVITY ANALYSIS (EEG-69)

The sensitivity of the performance assessment calculations of the CCA was first investigated by Helton (1996) in order to understand the relationship between several key parameters. His analysis used scatter plots and stepwise correlations to determine consistency among repository parameters. One weakness in the sensitivity analysis of Helton (1996) is that the sensitivity to parameters only applies to the actual range and distributions of sampled parameters used in the CCA calculations. Changes to either the range or distribution of one parameter may strongly affect the importance of other parameters, because release estimates vary by orders of magnitude for different combinations of parameter values. A case in point is the brine reservoir compressibility, which has been determined to have insignificant influence on the total release. The brine reservoir pressure and reservoir volume characteristics used in the CCA calculations reduce the importance of the brine reservoir to the calculated releases. It is entirely possible that the brine reservoir would be one of the most important contributors to large releases in calculations using more appropriate characteristics.

The limitations of the sensitivity analysis performed by Helton (1996) prompted the EEG to conduct their own analysis, by changing selected values or the range of selected values that were used in the CCA. This type of sensitivity analysis would truly distinguish the important parameters of repository performance, while testing the robustness of the codes involved. The analysis also allowed for the testing of the limit to which the disposal system would fail under extreme conditions. This is also useful in characterizing the important parameters.

2.2.1 Borehole Intrusion Rate

The consequence of future human intrusion scenarios into the Waste Isolation Pilot Plant was investigated in the CCA (U.S. DOE, 1996c). These scenarios were firmly established by EPA guidelines in 40 CFR Part 194 (U.S. EPA, 1996), and included the possibility of mining and deep and shallow drilling for resources.

The guidelines state in 40 CFR Part 194.33 that the likelihood of a drilling intrusion into the Delaware Basin must be calculated by considering the frequency of drilling over the past 100 years for all resources using a rate to be determined for the entire future of the WIPP. These numbers were calculated in the CCA, Appendix DEL (Tables DEL-3 through DEL-7) and were used to calculate the Complimentary Cumulative Distribution Function (CCDF) curves for the performance assessment calculations of the CCA. A total of 46.8 boreholes per km^2 per 10,000 years were estimated based on past drilling of resources at depths greater than 2150 meters, which equals 10804 boreholes per year in 23,102.1 km^2 (area of Delaware Basin).

The drill intrusion rate for the 10,000 year future of the WIPP was directly implemented in the CCDFGF model, and was calculated to be equal to 0.00468 boreholes/km^2/yr. However, future human activities are uncertain, and the rate was changed to test the effects on the CCA calculations.

The modeling associated with an increased borehole rate shows that a factor of approximately 23 is needed to reach the EPA release limit at a probability of 10^{-1} from values used in the CCA. The overall mean for the highest release tested, 4.68×10^{-1} boreholes/km^2/yr, exceeds the EPA limit of 10 EPA units at a probability of 10^{-3}. This does not seem to be likely, as the number of boreholes drilled in the Basin per 10,000 years would have to exceed one million, or 4,680 boreholes per km^2.

2.2.2 Probability of Brine Encounter at WIPP

The probability of encountering brine at the WIPP from an intrusion into the Castile Reservoir is uncertain. The probability was set to 8% in the CCA, and changed to a range of probabilities from 1% to 60% in the EPA's PAVT. However, the extent of the reservoir beneath the WIPP is unknown, and the influence of this parameter was tested at higher values at 50 and 100%. These values were based on the potential that the Castile reservoir size encountered by WIPP-12 (Chaturvedi et al., 1997) extends below the waste area.

The modeling only compared CCA values to the higher probability of encounter, and found the parameter to be unimportant in the CCA. The increase in releases from the 8% to 100% was only 0.1 EPA units (35 Ci). However, the synergistic affect of changing multiple parameters, especially those that affect the Castile Reservoir directly (pressure, volume, rock compressibility, etc.) may have a more profound result on the calculations, though these changes would have to result in releases of at least 1 EPA unit to significantly impact the CCDFs.

2.2.3 Castile Brine Reservoir Parameters

The pressurized Castile brine reservoir that underlies the Waste Isolation Pilot Plant has been the subject of many controversies on its extent and importance (Neill 2/7/97 and 3/14/97 in Appendices 8.1 and 8.2; Silva, 1994; Dials, 1997c; Beauheim, 1997). The performance assessment calculations of the CCA recognize the fact that the brine could play a significant role in the degradation of wastes and waste container, if an inadvertent drilling intrusion were to pass through the repository to the brine pockets below, by assigning two of the six scenarios to calculate the effects of the breach. However, the characterization of the parameters associated with the reservoir were undermined by associating them to data that clearly lies outside of the domain of the repository. The more realistic parameter values proposed by the EEG could potentially demonstrate higher direct brine releases to the surface, affecting the compliance with the containment requirements in the EPA standards of 40 CFR 191.13. Calculations were performed using more reasonable parameters for the simulation of Castile brine migrating into the repository.

Reservoir parameters used in performance assessment calculations were derived from well information that lies mainly outside the domain of the WIPP repository. The well distances ranged from 6 km (3.75 miles) to over 17.6 km (11 miles) away from the repository center. New values were assigned to several parameters that describe the Castile brine reservoir based on WIPP-12 data that is more closely identified to the conditions at the repository. The WIPP-12 is located 2 km (1.2 miles) north of the repository. The well was originally drilled in 1978 and deepened in 1981 at the request of the EEG, and was the cause for the repository to be moved south after brine was encountered in the well. The well was recorded to have experienced brine flow when coring reached a depth of 918 meters (3012 feet) (D'Appolonia, 1982). While extending the well to depths greater than 1189 meters (3900 feet), a total of 80,000 barrels (3.36 million gallons) were allowed to flow from the well.

The parameters associated with describing the Castile brine reservoir include reservoir volume, rock compressibility, reservoir pressure, and permeability. The modeling of these parameters began with the two-phase flow code, BRAGFLO, and ended with calculations of solid and liquid waste released due to an inadvertent human intrusion. The outcome showed that there is no significant change in releases for the CCDF due to small changes in the reservoir parameters. However, it is expected that the CCDF curve would move closer to the EPA limit if the solubility of actinides in brine were increased above that assumed in the CCA and PAVT.

2.2.4 Solubility Modeling of Actinides

The solubilities of actinide species at the WIPP in brine solutions are of concern, especially since limited experimental evidence exist (if any at all) on the amount of each species in solution. In some instances, weak analogies are used between species with the same oxidation state to infer a "better" value than would be achieved through actual experiments. Other cases used, in what seemingly appears as a flaw in a model, absurd calculated solubilities. To bound the uncertainty in the values chosen for solubility, the CCA invokes a range from the median value assumed (U.S. DOE, 1996c, Appendix PAR) of 2 orders of magnitude below and 1.4 orders of magnitude above. For example, the solubility for the +3 actinide, which was inferred from Americium data, had a median value of $5.82x10^{-7}$ M, and ranged from $5.82x10^{-9}$ to $1.46x10^{-5}$ M. The distribution to the range was log-cumulative, where most of the values (59%) fall between -1.0 and 0.0 orders of magnitude from the median.

Due to the uncertainties, further modeling by the EEG was conducted on brine movement from the repository under inadvertent human intrusion scenarios. If the actinide species are readily soluble, the brine could be an important mechanism to release a significant portion of actinides to the accessible environment.

For brine to escape the repository and travel upwards through the borehole under blowout conditions, 1) pressures must be significant to overcome the hydrostatic force of the drilling fluid, and 2) sufficient brine must be available for transport. Both conditions have been met in many of the realizations in the performance assessment calculations of the CCA. However, due to the assumed low solubility of actinides in brine, the consequence of a direct release of brine to the surface was minimal. For example, the mean release of radionuclides in the CCA through a direct brine release was 0.04 EPA Units (14 Ci) at the 10^{-3} probability, compared to spallings or cuttings and cavings, each having releases of 0.2 EPA Units (70 Ci).

The physical and chemical aspects of the repository were challenged by the EPA in an evaluation of the CCA, called the Performance Assessment Verification Test (PAVT). The EPA changed several parameters for the disposal system to test the uncertainty associated with the range of uncertainty in the parameter values. The test merely evaluated several parameters that could have significant affect on compliance, changed them to different numbers found to be more reasonable by the EPA, and reran the calculations. Some changes involved the solubility of the actinides in a brine solution by assuming a different speciation of minerals associated with the MgO backfill material, which lowered the median solubility limit for most actinides. The new set of solubility values came from the same flawed code used to establish the original set of numbers, and no new experiments were conducted to verify any of the values.

The results of the PAVT showed a large overall increase in the amount of brine to the surface upon intrusion, yet only nominal increase in release of actinides. This was expected, since the median solubilities were decreased by the EPA to be as much as 2 orders of magnitude for the +4 radionuclides. The effect on compliance from the changes shifted the CCDF for the direct brine release scenario closer to the compliance limit by 0.15 EPA Units. The changes are minimal, since 10 EPA units of release are needed to fail compliance at the 10^{-3} probability.

The problems with both models of the CCA and PAVT prompted the EEG to conduct bounding calculations on solubility. The first set of model experiments assumed that the Plutonium was of the +5 oxidation state, and used +6 values based on the work by Reed et al. (1994), Reed et al.

(1996), and Rao (1996). The values were only nominal increases above the CCA values for Plutonium in the +3 or +4 oxidation state for Salado Brine, but upwards of 10000 times for Castile Brine.

The modeling changes began with input files of the source term for PANEL. The changes were quite easy, and the analyses were complete in a matter of hours. The results showed that increases in solubility with CCA brine release volumes had limited effect on compliance with an overall increase on the mean CCDFs by 0.09 EPA Units. Even when the solubility was pushed to absurdly high values, the maximum release was limited by the availability of the actinide source. At a solubility of $8x10^{-3}$ M (compared to the CCA's $4.4x10^{-6}$ M for Pu+4 in Salado brine), the overall mean for direct brine release was increased from 0.04 to 1.3 EPA Units.

The second set of modeling experiments took the extreme position of assuming the solubilities of all actinides in different mineral species of MgO between the conversion of brucite to magnesite. In particular, calculations by Novak (1997) show values of actinides in the presence of magnesite, nesquehonite, hydromagnesite, and no backfill. CCA calculations assumed the long-term mineral species for MgO to be magnesite, and the PAVT assumed hydromagnesite. Yet, experiments could not prove the existence of either, and only showed hydromagnesite-like or proto hydromagnesite (Sandia, 1997). These other mineral species looked more like nesquehonite, and it seems difficult to justify the presence of either mineral phase assumed by the DOE and EPA.

Bounding calculations were performed on conditions resulting in the highest solubilities in the repository. These included nesquehonite and no backfill. For the nesquehonite simulations, it was assumed that the mineral would persist for the entire proposed history of the repository, and only median values were used. The assumption of the long-lived intermediate species is an overestimate on the expected conditions, to better understand performance of the repository. behavior. Similarly, calculations without the MgO backfill are intended to better understand the repository behavior.

Table 1 shows the solubility factors used to achieve solubility values from Novak (1997). The values have been log transformed for use in the input files to change the values that were established in the CCA. For example, SOLAM3-SOLCIM for nesquehonite increases the solubility of Am+3 in Castile Brine by 1.516 orders of magnitude, whereas SOLAM3-SOLSIM decreases the solubility by .277 orders of magnitude. The changes were made in the source term files, for running of PANEL and NUTS.

In addition to solubility changes from the CCA, the Salado transport files from the PAVT were used for transport calculations of NUTS and PANEL. The PAVT calculations exhibited higher repository pressures, hence larger direct brine releases upon intrusion. The maximum effect would be noticed with both changes together.

One curious observation from Table 1 shows that the solubility of nesquehonite in the +4 oxidation state (Pu+4, U+4, and Th+4) is higher than would be the case without any MgO backfill. Yet, one must keep in mind the context of these number, and remember that they are simply computer generated numbers, which are under much scrutiny. They do however provide a reference point in which compliance can be studied. If it is found that actual experimentation leads to solubility values less than those of Table 1, but slightly higher than the CCA values, one can interpolate compliance releases from existing CCDFs on probabilities and releases.

	Nesquehonite		No Backfill	
	SOLCIM	SOLSIM	SOLCIM	SOLSIM
SOLAM3	1.51616	-.27709	4.48678	3.83714
SOLPU3	1.51616	-.27709	4.48678	3.83714
SOLPU4	5.23242	2.15588	4.06695	2.05552
SOLU4	N/A	2.15588	N/A	2.05552
SOLU6	0.95861	0.96357	0.95861	0.96357
SOLTH4	5.23242	2.15588	4.06695	2.05552

Table 1. Solubility Factors for SOLCIM and SOLSIM

The results of running new solubility values can be seen in Figure 2. The figure shows the overall mean of all processes combined as they relate to compliance. In addition, the PAVT direct brine releases were run with the slightly higher CCA solubilities. The most distinct feature of the figure is the shoulder of the high solubility models that extend below the 10^{-1} probability limit. The "shouldering" is the effect of increased releases due to the direct brine release. Since the Pu+4 and Th+4 (although minor) solubilities increased over 5 orders of magnitude, the release due to this mechanism is expected to increase significantly as well. For example, the CCA median value for +4 actinide solubilities in Castile brine was 6×10^{-9} M. If one assumes 100 m^3 of Pu^{239} brine, then it is expected that the release is 2.5×10^{-5} EPA units. If the solubility is increased by $10^{5.23}$ as seen in Table 1., then it is expected that 4.24 EPA units are released to the accessible environment. Therefore, the CCDF for higher solubilities would be closer to the EPA limit.

The consequences of higher solubilities, as seen in Figure 2 are quite high. The overall mean

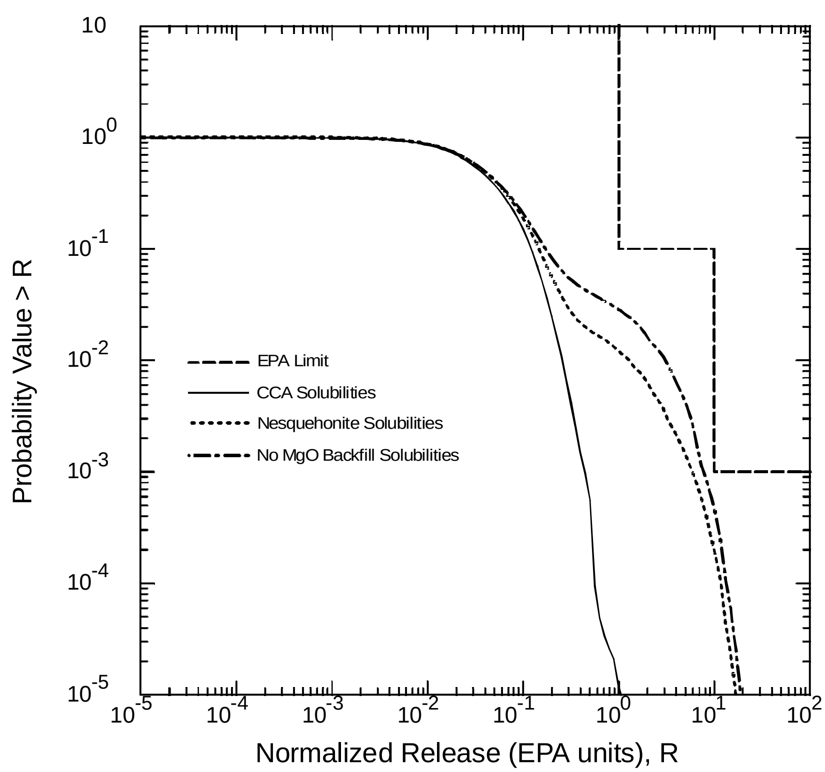

Figure 2. Overall Mean of Normalized Releases for Modeling of increased solubilities using Nesquehonite and 'No Backfill' Values compared to CCA values.

release for the CCA and PAVT were 0.2 and 0.4 EPA u at 10^{-3} probability, respectively. The overall mean for the increased solubilities of nesquehonite and 'no backfill' are 6.0 and 8.0 EPA units at the 10^{-3} probability, respectively. The limit for compliance, according to 40 CFR Part 194 is 10 EPA units. Therefore, it appears that even high solubility values do not cause the disposal to be out of compliance with the EPA regulations. However, there is a deeper issue that one cannot dismiss, that is far less superficial than the previous statement. It deals with the consequences in small changes of solubility and variability in the actual values. Are we so certain that the solubilities of Plutonium or Uranium, in any oxidation state, are less than the values presented in the CCA or the PAVT? How did we arrive at these numbers? Are there experimental evidence to back up the claims made in the CCA that deals with the oxidation state analogy between Am+3 and Pu+3? Once one really delves into the reasoning behind many of the fixed numbers associated with these actinides, many deficiencies appear in the reasoning, and confidence in the values used to show compliance declines.

2.2.5 Flow and Transport Modeling within the Culebra

The transport of radionuclides to the accessible environment can occur in two ways: upwards from the repository through a borehole to the surface into the biosphere, or laterally through the stratigraphy of highly conductive layers across the Land Withdrawal Boundary (LWB). The second method was investigated by modeling the Culebra aquifer of the Rustler. The CCA and PAVT include Culebra modeling and its consequence of transport across the LWB in the CCDF curves. The CCA showed only 1 of 300 realizations to cross the boundary in 10000 years, with the PAVT showing a significantly higher impact on the Culebra. The end result of increased transport across the LWB in the PAVT had little to no effect on the CCDF.

EEG's concern about of the modeling of the Culebra begins with the assumptions used in parameters that describe actinide behavior with the Culebra dolomite. When the actinides are directed along flow paths after a release to the Culebra, the transport will be retarded by the interaction of the actinides with the Culebra matrix. The interaction is known as sorption (either absorption or adsorption, and is usually non-reversible), and different types of sorption, called isotherms, describe the interaction between the two constituents. The Culebra was characterized as having a linear isotherm with the actinides, and the parameters of the isotherm, known as the partition or distribution coefficient (K_d) were measured in laboratory experiments.

The same oxidation state analogy used to predict similar solubility of actinides was applied to the distribution coefficient. Therefore, many of the actinides' K_ds were not actually measured and it is not clear what the consequence would have been with better values. Though it is well known that high K_d values will retard the actinide species sufficiently to inhibit transport, it is the low K_d values that are of concern. For example, it was shown by Blaine (1997) that K_d values higher than 3 ml/g for most actinides would sufficiently retard transport, and an insignificant portion of the actinides would cross the Land Withdrawal Boundary. Only one actinide in the PAVT, U+6, has K_d values as low as 2 ml/g.

It is also well known that some waste constituents in the WIPP inventory will bind themselves to the actinides to further lower the K_d values. EDTA, for example, is used to bind with Plutonium for cleanup purposes. Other organic ligands in the waste will have similar effect. Furthermore, the lack of measurements decrease the confidence in values used in the CCA and PAVT, and this prompted the EEG to continue with additional calculations, testing the effects of lowered K_ds on the disposal system and compliance.

The interaction between releases from the repository and transport of actinides require a lengthy discussion, and will not be discussed here. It is possible, due to the set up of the codes, to do calculations that assume any percentage of the actinide's mass to completely bind with EDTA and migrate unretarded through the Culebra matrix. Therefore, additional calculations were performed assuming 1% of Pu (+3 and +4) having a K_d=0 ml/g.

The results of the calculations show that the overall mean of the releases through the Culebra was 0.0001 EPA Units at the 10^{-3} probability. Since a large number of realizations crossed the LWB with significant releases, it was reasoned that the mass of radionuclides reaching the Culebra was the limiting factor. This was proved when the models of higher solubility were combined with transport modeling, and the overall mean for release from the Culebra was increased to 0.31 EPA

Units.

Another model was proposed in which the extent of potash mining within the controlled area Land Withdrawal Boundary was extended to include lower grade potash ore. Potash mining occurs in the McNutt Potash Zone of the Salado, which is about 200 meters below the Culebra. The effect of potash mining in the Delaware Basin would cause subsidence to the overlying units, and hence having a possible detrimental consequence from increased transport of radionuclides. The CCA established the criteria for considering the effect of mining by assigning a multiplying factor to the transmissivities of the Culebra, which increased the velocities above the mined region.

The extent of mining is debatable, and depending on which map is used determines the possible economic viability of the resource. In addition, new methods of mining such as solution mining could extract lower grade minerals more readily. Therefore, the EEG included a larger area of mining in a new flow model, yet keeping the same parameter changes that were used in the CCA. It is feasible to change other parameters or include new ones, but due to the limited time available to the project, this was not thoroughly investigated.

The results of extending the areal minable region within the Culebra had little to no effect on the transport of radionuclides across the Land Withdrawal Boundary, though it did change the flow patterns slightly. The limit of transport is sorption, and the PAVT values for K_d were retained for Uranium. The combination of low K_d and larger mining area was studied with Plutonium, again using the 1% K_d=0 ml/g. Again, the amount of initial mass injected to the Culebra crossing the Land Withdrawal Boundary was significantly higher, but limited by the amount reaching the Culebra.

Lastly, the combined effect of extended mining, low K_ds, and high solubilities were combined in an effort to test the synergistic effect of all the previous results. The overall mean for the release through the Culebra was as high as 1 EPA Unit (or 350 Ci). The addition of the Culebra releases to the overall mean of all combined releases moved the CCDF closer to the EPA compliance limit by 12%.

2.3 ACTINIDE SOLUBILITY

2.3.1 Introduction

Except for the final performance assessment submitted to EPA (U.S. DOE 1996c), actinide solubility had always been identified as one of the key parameters in calculating the 10,000 year performance of the repository. During the early efforts to develop the performance assessment, it was quickly recognized that there was a dearth of actinide solubility data for anticipated conditions of high salinity and high pH for the complex heterogeneous waste chemistry. Moreover, a reliable estimate of the solubility could not be calculated due to the lack of thermodynamic data (Brush and Lappin, 1990). Nonetheless, the development of the PA codes required some estimate for the range and distribution of solubility values for the each of the actinides. In lieu of data, the early PA calculations used a solubility range and distribution recommended by Brush (1990). The solubility of each actinide was assumed to have a log uniform distribution from 10^{-9}M to 10^{-3}M with a median value of 10^{-6}M. However, the PA effort was cautioned about the limited use of these values (Brush, 1990; Brush and Lappin, 1990).

Brush's 1989 estimate of radionuclide solubilities, 10^{-6}M with a range of 10^{-9}M to 10^{-3}M, were a source of concern for another reason. The relatively high values suggested the possibility of significant releases when used in radionuclide-transport calculations (Brush, 1990). There was also concern about the wide range of estimated actinide solubilities. Brush noted that it would be desirable to narrow the range as soon as possible and advocated continuing the ongoing experimental work which would require another two or three years to obtain enough data for comprehensive calculations.

Meanwhile, for the 1991 and 1992 PA, Sandia National Laboratories conducted an elicitation in which four outside scientists collaborated to estimate the median value and range of solubility for each actinide in each oxidation state. However, the results of this exercise did not narrow the range. The estimated range of solubilities expanded from six orders of magnitude to twelve orders of magnitude depending on the actinide and the oxidation state (Sandia, 1991, Vol. 3, pp.

3-62 to 3-66). Moreover, the expected actinide concentrations were much less than those estimated by Brush. For example, the median solubility value for the Pu^{IV} and Pu^{V} decreased by more than three orders of magnitude to 6×10^{-10}M. Not only were the new values lower, this median value was not even in the range recommended by Brush. At the bottom of the range, the solubility for Pu^{V} was estimated to be as low as 2.5×10^{-17}M.

The 1991 and 1992 PA attempted to capture the effects of oxidation on solubility. For these two PA efforts, the amount of each actinide in each oxidation state was estimated from diagrams of actinide oxidation states as a function of Eh and pH (Sandia, 1992, pp. 3-67 to 3-70). Similar methods were used in the 1992 PA with some minor adjustments (Sandia, 1992, Vol. 3, 3-38 to 3-43).

Sandia did not publish an annual performance assessment for the years 1993 and 1994. Rather, the calculation efforts were directed toward the development of a systems prioritization methods (SPM). SPM was advanced as a management decision making tool needed to identify the best use of resources to demonstrate compliance with the EPA Standards.

As a result of the SPM exercise, Novak et al. (1994, p. 7, 29) identified problems with the actinide solubility values used in the 92 PA calculations. The mobile actinide concentration model in the 1992 PA was characterized as the "intuition and impressions of four individual experts." Furthermore, the thought processes used by the members of the panel to generate their predictions had not been documented, making peer review of their reasoning difficult. Hence, Novak et al. maintained that the values used in the 92 PA were indefensible and should not be used in future performance assessment calculations. Novak et al. (1994, p. 29) also argued that any concentration less than 10^{-10}M would not be defensible. Such a low value for concentration could never be confirmed by a measurement because it was below the limits of detection.

Determination of solubilities focused on modeling the solubilities under different repository chemistries. Rather than use a more widely tested model, such as PHREQE or EQ3/6, the project developed its own unique model, FMT. The FMT model would be used by performance assessment to calculate actinide concentrations in Salado and Castile brines. However, the project still needed data for the development of the model and there was no data forthcoming for review. As noted in the October 1996 NAS/NRC WIPP Committee report:

> Overall, the scientific program outlined by DOE for study of the source term is adequate, provided that the program is carried to completion. Because the program at this time consists largely of work planned or in progress, it has not been possible to critically review experimental results or to judge whether these results are used appropriately in the PA analysis (NRC 1996, p. 62).

The DOE submitted the final Compliance Certification in October 1996. The EPA published its technical review of the actinide source term program and modeling in October 1997. EEG asked Dr. Virginia Oversby to evaluate the DOE modeling efforts and the EPA review. Her evaluations, which are included with this report, identified many of the issues summarized in the EEG letter of December 31, 1997, to EPA (Appendix 8.3). Her reviews of the DOE CCA and other documentation are attached as Appendix 8.4a. On February 20, 1998, EEG met with scientists from Sandia National Laboratories and Dr. Virginia Oversby and Dr. Rodney C. Ewing to discuss the actinide solubility program results. The letters which they prepared subsequent to that meeting are attached as Appendices 8.4b and 8.4c. Dr. Oversby's review of the EPA technical support document is included in Section 2.3.2.

The FMT model is unique to WIPP and is not generally used elsewhere. Calculations using the FMT model result, for example, in a difference of 19 orders of magnitude between the projected solubility of thorium pentacarbonate in the Castile brine versus the Salado brine. This is hard to explain on the basis of differences in the brine compositions. Hence the code becomes suspect. It appears that the EPA verification was limited to an exercise in which EPA used the same computers, codes, and database (after correction of some errors in the database) as DOE, to determine the same numerical values. This is not the standard of verification that one normally applies to chemical modeling codes. Verification would require, at a minimum, an analysis and demonstration that the FMT code correctly solves the simultaneous equations, a thorough comparison with the results of calculations using a code that is used more widely in the modeling community, and a demonstration that the calculations are consistent with all relevant published data. For example, as a preliminary analysis, it would have been more informative if a widely used code such as EQ3 or PHREEQE had been used with the FMT database and then FMT had been used with a database from some other modeling group.

Plutonium will account for 82% of the WIPP radioactive inventory 100 years after closure. The CCA maintains that the plutonium will exist either as Pu(III) or Pu(IV). However, the plutonium data were not used for developing the FMT model to predict the solubility of Pu(IV). Rather, the CCA relied on data for uranium and thorium as analogs. But there are long recognized concerns about relying entirely on the oxidation state analogy to derive thermodynamic constants for modeling complex electrolyte systems. As stated in the NAS/NRC WIPP Committee report (NRC, 1996, p. 129):

> Although the oxidation state model (the assumption that the chemistry of a given oxidation state is similar for all of the actinides) is an appropriate beginning to a difficult problem, deviations from the oxidation state analogy are well known in natural and experimental systems. Substantial experimental verification will be needed to establish the limits of this analogy.

In its technical support documentation, EPA discusses the shortcomings of the solubility uncertainty ranges advanced by DOE. There is no direct basis for the uncertainty ranges for actinides in oxidations states +4 and +6. Moreover, the uncertainty ranges for oxidation states +3 and +5 are derived primarily from non-actinide data. Nonetheless, EPA has accepted the ranges as adequate, commenting “It is not clear that including more data for the other actinide state would appreciably change this range” (U.S. EPA, 1997c). The argument is weak. It also remains unclear that the range adequately brackets uncertainty for a population for which data have not been examined.

In the solubility calculations, the CCA inappropriately discounts the role of organic ligands on plutonium solubility. The CCA provides information on the amounts and complexing properties of EDTA and then argues that other organic ligands, such as citrate, will be unimportant despite the fact that citrate is the most abundant water-soluble organic constituent. Citrate forms extremely strong complexes with actinides in the +4 oxidation state [e.g. Th(IV)], but very weak complexes with other cations. Moreover, the DOE and EPA have each assumed that the actinides and the brine would be evenly distributed and well mixed throughout the repository. EEG believes that this is an inappropriate assumption. The plutonium and citrate are probably located in the same drums. These waste forms result from chemical separations of Pu and do not fit the classic description by DOE of TRU waste as contaminated tools, rags, gloves, booties, etc. The solubility of the plutonium for these waste forms must also be calculated as a very stable plutonium citrate complex where other cations in the brine diffusing into the drum cannot compete effectively with the complexed actinides (IV).

Perhaps the most important questionable assumption made in projecting the solubility values used in the CCA and the PAVT is the presence of hydromagnesite as the dominant stable mineral species resulting from the MgO backfill. DOE's experimental efforts with MgO predominantly produced nesquehonite, a magnesium carbonate mineral, with the later appearance of an unidentified phase. Hydromagnesite was not formed in the experiments reported by the DOE (Sandia, 1997); a hydromagnesite-like unnamed mineral is reported. The chemical composition of this mineral is in fact more like nesquehonite. The DOE and the EPA believe that "hydromagnesite will be the metastable hydrated magnesium carbonate phase and nesquehonite will be an intermediate phase." (U.S. EPA 1997c). There is no experimental data for the length of time that nesquehonite is expected to exist. The distinction between the projected hydromagnesite-dominated or nesquehonite-dominated chemical environment in the repository is important because the actinide solubilities in the presence of nesquehonite are 3 to 4 orders of magnitude higher than in the presence of hydromagnesite.

The EEG has investigated the effect of actinide solubilities on the mean CCDF plots, using the EPA's PAVT releases, and making no other changes (Neill Letter dated December 31, 1997 –

Appendix 8.3 of this report). The investigation included the "CCA" solubilities, "no backfill" solubilities, and "nesquehonite" solubilities. The overall mean CCDF curve for "nesquehonite" solubility moved one order of magnitude closer to the compliance limit at 10^{-3} probability compared to the CCA solubilities.

The EEG therefore recommends that the EPA reexamine these issues and provide additional justification for the CCA and the PAVT solubility values. If convincing justification is not available, then the "no backfill", or "nesquehonite" solubilities should be used in a new performance assessment calculation. EEG concerns are summarized below.

1. The FMT model is unique to WIPP. EEG found that the model predicts differences for actinide sulfate and carbonate solubilities that can not be explained by chemistry, thus leaving the reliability of the calculations suspect. The unexpected results need to be explained or the model needs to be re-examined for possible problems with the code.

2. Rather than use an extensive plutonium data base, the FMT predictions relied on thermodynamic data for other elements and an oxidation state analogy argument. EEG recommends that the calculations be performed using data for plutonium and the values for solubility and complex ion formation contained in the peer-reviewed data compilation by OECD/NEA.

3. EEG agrees with EPA's documentation of the shortcomings of the solubility uncertainty ranges advanced by DOE. However, EPA has accepted the ranges as adequate based on a weak argument. EEG recommends that the uncertainty range needs to be determined with the appropriate plutonium data.

4. In the solubility calculations, the CCA inappropriately discounts the role of organic ligands on plutonium solubility by arguing that EDTA is the strongest complexing agent. But citrate forms very strong complexes with actinides in the +4 oxidation state and very weak complexes with

other cations. Thus, the solubility of a stable plutonium-citrate complex in individual waste containers needs to be calculated.

5. There are serious unanswered questions about the impact of magnesium oxide backfill on the solubility of the actinides. It is proposed that magnesium oxide will reduce the solubility of the actinides by controlling the pH. But, it is not known how long the early reaction product, nesquehonite, will persist. The FMT model calculates that the presence of nesquehonite drives the solubility of the +4 actinides, such as plutonium, higher than in the no backfill case. This requires further investigation.

2.3.2 Comments on "Technical Support Document for Section 194.24: EPA's Evaluation of DOE's Actinide Source-Term" - prepared by V. M. Oversby

2.3.2.1 General Comments

The EPA evaluation of expected redox states, solubility, and speciation of actinides under WIPP disposal conditions was very narrow in its scope. In general, only the references cited by DOE and the work done by the DOE contractors was discussed. The evaluation would be considerably strengthened, and might reach different conclusions, if relevant results published in the open literature of studies conducted by other scientists were discussed.

The EPA has limited their review of the DOE solubility calculations to an exercise in which EPA used the Sandia computers, codes, and databases to determine whether they could get the same numerical values for results if they tried to duplicate the work done by DOE. It would have been very surprising if they had failed to find agreement under those conditions. A more reasonable evaluation would require a comparison of the results of calculations using a code that is used more widely in the modeling community with those obtained by the Sandia FMT code.

There has been no evaluation by EPA of the thermodynamic properties data used in the database for the solubility calculations. There has been no attempt by EPA to assess the degree to which the calculations might represent the conditions expected for WIPP disposal. Both of these tasks are needed in order to determine whether the DOE calculations have any validity.

In evaluation of the effect of organic ligands on the mobilization of actinides, EPA considers only the case of homogeneous equilibrium, in which the entire actinide inventory in the repository is well-mixed with a very large volume of brine that inundates the repository. This is an unrealistic and non-conservative model for evaluation of the effect of organics. In addition, EPA bases their evaluation of the ability of organics to mobilize actinides on an analysis that only considers EDTA. While this analysis gives the correct result for the importance of EDTA, it does not speak to the issue of the importance of citrate in the waste and its ability to increase the mobility of Pu.

2.3.2.2 Comments by Section

Section 2 "Solubility and Actinide Oxidation States"

Comments are limited to U(IV), Th(IV), and Pu (all oxidation states).

The EPA document summarizes the discussion of expected actinide oxidation states and concurs with the DOE position. In doing this, the EPA overstates the content of the DOE SOTERM Appendix to the CCA. EPA states on p.5 "DOE provides a summary of the literature and a discussion of experimental results for thorium, uranium, neptunium, americium, curium, and plutonium." Unfortunately, the DOE document limits itself to a discussion of the expected oxidation states for these elements and does not discuss the chemistry sufficiently. For example, after it is concluded that the expected oxidation states for U will be IV and VI, the chemistry of uranium IV is not further discussed. This is unfortunate, because published data on the solubility of UO_2 in concentrated synthetic brines could have been used to evaluate the validity of the claims made for the use of the Th(IV) model for representation of all actinide (IV) species. See discussion of experimental results of DePablo et al. (1995) in Oversby (1997). It is surprising that EPA did not discuss this lack of evaluation of the model against published data, since the necessity for such evaluations had been pointed out by the National Research Council review of the WIPP project as recently as 1996 (NRC, 1996). In their review, the committee states on p.129 that "Although the oxidation state model (the assumption that the chemistry of a given oxidation state is similar for all of the actinides) is an appropriate beginning to a difficult problem, deviations from the oxidation state analogy are well known in natural and experimental systems. Substantial experimental verification will be needed to establish the limits of this analogy."

The oxidations states expected by DOE for Pu in the WIPP repository are III and IV. Any Pu(V) formed is expected to be rapidly reduced by iron. EPA concurs with this conclusion; however, Pu(V) is observed as a long-lived transient in many laboratory experiments. Pu(V) may be formed as a result of radiolosis reactions in the brines and while its total abundance in the repository is likely to be low, it might be significant as a transient species in some waste containers. The release scenarios considered important for WIPP are those involving human intrusion, with drilling through the repository to a brine-containing formation below the repository. Upwelling of brine from this lower layer through the repository might allow rapid transport of brines containing some Pu(V) to the surface.

The inclusion of Pu(III) for a potential redox state is based on work by Felmy et al. (1989). Their experiments used Pu(III) maintained in that redox state by adding Fe powder to the solutions. The solubility of $Pu(OH)_3$ was measured in dilute solutions and brines. The redox state of Pu was verified by using chemical extraction methods; however, the method used measured Pu(III) + Pu(IV), so there is not positive identification of Pu(III) content. At pH 9 and above, the concentration of Pu was below detection limits (Felmy et al., 1989). This would suggest that Pu(III) needs to be considered only up to pH 9 in modeling calculations if metallic Fe is present, which it will be in the form of WIPP disposal drums. Above pH 9, the upper limit for Pu(III) should be set by the detection limit in the Felmy et al. (1989) experiments as 10^{-9} M.

The EPA claims on p.5 that "The predominance of U(IV) requires extremely reducing conditions, that while possible for the repository, cannot be predicted with certainty." This statement is at odds with the claim that the redox conditions will be controlled by the presence of metallic iron and its oxidation to Fe(II). The redox conditions imposed by the Fe(O)/Fe(II) buffer are much more reducing than those required to stabilize U(IV) as UO_2. This fact was used by Rai et al. (1995), who added Fe powder to their experiments concerning solubility of U in carbonate and bicarbonate solutions in order to assure the absence of U(VI). Available experimental data for U(IV) are relevant for use in estimating solubility of U under WIPP conditions and also for use in comparison with estimates of solubility for Pu based on the Th(IV) model.

Section 3: "Effects of the Magnesium Carbonates on Predicted Repository Conditions Due to MgO Backfill"

The EPA evaluation claims that DOE described (Sandia, 1997) experiments in which "the reaction of MgO with brines was observed to result in the rapid formation of nesquehonite, which then converted to hydromagnesite within days." EPA concludes "Consequently, nesquehonite cannot be expected to persist in the repository environment."

The Sandia report (Sandia, 1997) does describe results of reaction of MgO with brines. Nesquehonite is found as an early reaction product. Unfortunately, hydromagnesite is never identified in the reaction products, even though sections in the Sandia report claim that a poorly characterized phase tentatively identified to have the composition $MgCO_3 \cdot 3H_2O \cdot MgCl(OH)$ (PDF7-278) (no name given) was hydromagnesite-like or even that it was protohydromagnesite. The chemistry of the phase found is quite different from that of hydromagnesite $[(MgCO_3)_4 \cdot Mg(OH)_2 \cdot 4H_2O]$ and contains a major structural unit with the same chemistry as nesquehonite $(MgCO_3 \cdot 3H_2O)$. There is no evidence discussed in the Sandia document that shows disappearance of nesquehonite under conditions relevant to WIPP. With the evidence at hand, one must conclude that nesquehonite will, at the very least, be a very long term metastable phase under WIPP repository conditions. So long as CO_2 can be expected to be released into the brines - from any source - and MgO is present in the repository, the reaction to produce nesquehonite will occur. If nesquehonite is present in the phase assemblage in the repository system, it will fix the dissolved carbonate activity at levels higher than those appropriate for hydromagnesite, even though hydromagnesite may also be present. Absence of nesquehonite requires experimental data to show the rate of conversion of nesquehonite to another phase, as well as data to determine the time for an end to the production of new nesquehonite. Appropriate data are currently lacking for both of these items. As noted by EPA (p. 8), the discussion of the correct phase assemblage for the Mg-Carbonate system under WIPP conditions “may seem academic but is important because of the potential effect on the solution conditions and consequent predictions of actinide solubilities”.

Section 4: “FMT Modeling Results”

This section describes the work done by EPA to evaluate the FTM modeling code and results obtained using that code for prediction of brine chemistry for WIPP conditions.

EPA went to Sandia and used the FMT code and data base there to rerun the same cases as reported in the CCA and subsequent reports on MgO stability. They were able to reproduce the numerical values (after correction of some errors in the data base). EPA considered that this constitutes “verification” of the results. This is not the standard for “verification” that one normally applies to chemical modeling codes.

Normally, verification of a numerical model requires that one determine that the model does what it claims to do. We do not know whether the FMT code correctly solves the system of simultaneous equations - which is what verification would mean in this case. The only thing we know is that it is not so numerically instable as to produce wildly divergent numerical solutions to the same problems using the same data.

There has also not been verification that the thermodynamic data in the database correctly represent what is known about actinide chemistry in brines. The results using the “modified” database that produced lower Th predicted solubilities still seem to have predicted far more Th-pentacarbonate than one would expect based on the experimental studies of Östhols et al. (1994) who did the measurements of ThO_2(am) solubility that provided the basic thermodynamic data for the Th-pentacarbonate association constants. The results are also inconsistent with the measurements of Th solubility in Na-carbonate and Na-bicarbonate solutions (Rai et al., 1995) that showed that a dissolved carbonate concentration of 0.1 mole per liter was needed before a significant increase in Th solubility due to carbonate complexation was seen. The EPA results reported in tables 4-8 and 4-9 do not show speciation for Th; however, those contained in the Novak (1997) memo do. The following table compares the calculated results for dissolved carbonate, bicarbonate, $Th(CO_3)_5^{6-}$, $Th(OH)_3(CO_3)^-$, and H^+ for nesquehonite and for 5424 hydromagnesite in SPC brine.

Table comparing speciation of Th for different Mg-carbonate phases in SPC brine. Data from Novak (1997). Concentrations in moles/kg of brine.

Solution species	Nesquehonite	5424 Hydromagnesite
Carbonate	9.9×10^{-4}	2.17×10^{-5}
Bicarbonate	2.15×10^{-3}	4.7×10^{-5}
$Th(CO_3)_5^{6-}$	7.2×10^{-4}	3.6×10^{-12}
$Th(OH)_3(CO_3)^-$	5.7×10^{-7}	1.25×10^{-8}
H^+	4.3×10^{-10}	4.3×10^{-10}

Note the predicted dominance of the Th-pentacarbonate complex for the case of solubility controlled by nesquehonite present, even though the dissolved carbonate and bicarbonate concentrations are about a factor of 50 below where one would expect this complex to begin to become important.

The FMT code was developed at Sandia and has not been generally used in the community that does geochemical modeling, nor by the other groups world-wide that do performance assessment of radioactive waste repositories. Over the years, there have been a number of case studies conducted to compare the results of calculations of the same problem using different modeling codes and databases. It has been found that considerable differences in results have occurred, even when the codes were thought to be using the same solution algorithms and databases. It would be more instructive, from the point of view of verification of the FMT calculations, if a more widely used modeling code, such as EQ3 or PHREEQE had been used with the Sandia database and then FMT had been used with a database from some other modeling group. It would probably be sufficient to do calculations for each brine with nesquehonite and one of the hydromagnesite phases in sequence controlling the carbonate solution levels.

The subject of validation, which is the degree to which the modeling results can be expected to produce a correct representation of a real, complicated, natural situation is not discussed in the EPA evaluation. Validation of a code is normally considered an essential part of code development prior to use in performance assessment.

Note: There are typographical errors in Table 4-2, Step 4, Novak for Th(IV) concentration (should be E-06, not E-09), and Table 4-3, Total Th, verification (b) column (should be E-06, not E-09).

Section 5: "Review of the Uranium (VI) Solubility"

In this section, EPA critically reviews the assumptions used by DOE in estimating the solubility of U(VI). EPA correctly notes that the assumption by DOE that solubility can be estimated for U(VI) in WIPP by assuming that carbonate is absent is incorrect. EPA provides suggestions for U(VI) speciation and for solubility controlling solids. They also correctly assess the relative importance likely for hydrolysis species of U(VI) as compared to carbonate species. It would be most useful if the critical methodology used by EPA for assessment of Section 5 were used to assess Sections 2, 3, and 4.

Section 6: "Actinide solubility uncertainty range"

EPA describes the method used by DOE to develop the estimate of uncertainties in solubility calculations for the actinides. This is most useful, since the CCA and references therein did not provide this information. Solubilities calculated using FMT were compared with the results of experimental measurements and the deviations between the calculated and measured values were the basis for the uncertainty distribution.

Not all experimental data were used in this evaluation. First, any solubility data with +6 oxidation state for actinides was eliminated because FMT could not calculate for +6 actinides. Experimental data for +4 actinides were also eliminated because "data available for the +4 model were found to have significant problems in the extrapolated regions and were thus determined to be inadequate for this analysis." EPA notes that this position is inconsistent with the statements in the CCA concerning availability of data for Th(IV) speciation in brines.

Elimination of +4 and +6 oxidation states meant that only +3 and +5 data were used in the uncertainty analysis. The distribution of experimental data used was 69% Nd(III)carbonates (104 measurements), 23% Am(III)carbonates, and 7% Np(V) in carbonated brines. Solubility data for Pu(III) data in brines was not included in the analysis, even though these data were used to obtain parameters for the Pitzer coefficients in the calculations.

EPA correctly notes that the estimation of uncertainties for +3 actinides based mainly on Nd data is somewhat problematical since Nd is not an actinide, even though its chemistry might be expected to be similar to +3 actinides. They also note that it is likely that the uncertainties in the solubilities of +4 and +6 actinides should be expected to be larger than those for +3, since it is for these oxidation states that it was found that insufficient data existed to make an analysis of uncertainty. It is particularly difficult to understand how an assessment of how well the Th(IV) data model the expected solubilities for U(IV) and Pu(IV) can be done if no comparisons are ever made between calculations and experimental results. The large changes in calculated Th solubility when changes were made to Pitzer coefficients after unacceptably high Th solubilities were calculated (see Section 4 in EPA review) suggests that uncertainties in predicted solubilities may be considerably higher than those given in the DOE CCA analysis.

The inconsistencies in speciation for Th in the FMT calculations when compared to the original work that derived the thermodynamic properties data that must be used in the calculations also points to considerably higher uncertainties than the -2 to +1.4 log units cited in the DOE CCA. The EPA concludes that the range cited by DOE is probably adequate and states "It is not clear that including more data for the other actinide oxidation state would appreciably change this range." It is equally true that it is not clear that the range adequately estimates uncertainty for a population for which data has not been examined.

Section 7: "Influence of Ligands and Complexants on Actinide Migration"

In this section EPA's stated purpose was to "determine whether DOE appropriately characterized organic ligands and humic materials on their potential to increase the mobilities of actinides and to evaluate DOE's approaches for representing such processes." EPA concluded that organic ligands will not increase actinide mobility.

EPA provides a lengthy section of introductory material, which describes complexation chemistry and factors that increase mobility of metals through complex ion formation. They then proceed to assume that brine will be present in the WIPP repository and will commingle with the waste during much of the repository's performance period. In essence, this is equivalent to the assumption made by DOE that the system could be modeled assuming homogeneous equilibria of brine and actinides. In other words, both DOE and EPA assumed that the actinides would be evenly distributed throughout the repository and that the brines would be well-mixed and have a uniform composition throughout the repository. This is unlikely to be the case and is certainly not appropriate for evaluation of the development of dissolved actinides inside a partially destroyed waste container, a scenario that is important with respect to assessment of human intrusion consequences.

In the DOE evaluation of the effects of organics and humic substances, the organics are treated in SOTERM as if they were homogeneously dissolved in 29,841 m^3 of brine. DOE then looked at the values of the complexation constants and concluded that EDTA formed the strongest complexes with actinides, so would be the most important organic ligand. EDTA also forms strong complexes with many other cations, so when DOE evaluated the complexation behavior of

EDTA they found that most of the EDTA would be associated with Ni. EPA disputes this conclusion based on their estimate of Ni solubility in nature, but in their own calculations of EDTA behavior they conclude that EDTA will not increase Th(IV) solubility because the EDTA will be complexed with Ca and Mg under alkaline conditions.

The abundance of EDTA in the wastes intended for WIPP is low; in addition, EDTA forms strong complexes with many cations. For both of these reasons it is reasonable to conclude that the EDTA present in the WIPP repository will not lead to an increase in actinide IV mobility. It is not, however, appropriate to conclude from an analysis of EDTA behavior that organic ligands will be unimportant under WIPP conditions. Citrate is the most abundant water-soluble organic constituent in the waste inventory listed in the SOTERM Appendix to the DOE CCA. Citrate forms an extremely strong complex with Th(IV), but much weaker complexes with other cations. For this reason, even in the presence of very high dissolved Ca and Mg, the citrate will preferentially form complex ions with the +4 actinides.

To model the behavior of Pu with citrate, we must also consider heterogeneous equilibria for organic complexation with the actinides. The main difficulty arises because the Pu in the waste is probably located in the same drums as the citrate, which is the dominant organic ligand. This is because these wastes arise from chemical separations of Pu and are not the type of waste described in the general descriptions of TRU waste as contaminated equipment, clothing, etc. To get an accurate estimate of the effect of organic ligands on Pu solubility, one must calculate the concentration of Pu as citrate complex inside a waste drum that has been breached, but can still provide a hindrance to mixing of the brine inside the drum with a larger pool of brine outside the drum. This will give a high concentration of Pu in solution as the citrate complex. Other ions will not compete with Pu sufficiently to prevent complex formation because the stability for (IV) actinide complexation - as shown by the stability constant for Th(IV) on p. 39 of the SOTERM appendix- is orders of magnitude larger than that for other ion complexes with citrate.

EPA discusses some work by Hummel (1993), who reports the effect of organic ligands under high pH conditions in cement pore waters. The high pH conditions do argue against complex formation by EDTA and other "conventional" organic ligands; however another possible ligand for increasing Pu(IV) solubility comes from the degradation of cellulose under high pH. Work in England has shown that degradation of cellulose can occur both through chemical processes at high pH and by radiation effects. The degradation products have been shown to increase the solubility of plutonium dramatically (Cross et al., 1989; Greenfield et al., 1992).

The discussion of humic substances in the EPA evaluation is very thorough. EPA concludes that DOE has probably overestimated the effect of humic materials on the mobilization of actinides, but agrees that the approach taken by DOE is conservative. The amount of +4 actinide carried by humic materials is estimated to be 6.3 times the amount actually in solution as dissolved species. This overestimation of the importance of humic substances on Pu mobility may balance, in part, the failure to consider the complexation of Pu by citrate. Some relatively simple calculations should be able to provide sufficient information to evaluate the relative importance of the under and overestimation of Pu speciation on total Pu mobility.

Section 8: "Microbial Effects"

EPA discusses the potential for microbial activity in WIPP and concurs with a DOE contractor assessment that "although significant microbial gas production is possible, it is by no means certain." Other aspects of microbial activity are also discussed and noted to have high levels of uncertainty associated with whether the activities will actual happen and, if so, how will they affect actinide mobility. In general, it is concluded that the effects of microbes are most likely overestimated.

The potential overestimation of CO_2 gas production was the driving force for adding MgO backfill to the repository to control the dissolved carbonate content in any possible brines. The use of MgO backfill is not without its own uncertainties. See discussions above concerning reaction products of MgO with brines containing carbonate and the resulting effects on the solubility of +4 actinides. It might be worth trying to get a more realistic picture of the potential for carbon dioxide production and to re-evaluate the need for the MgO in the repository. Another possibility would be to follow the NRC (NAS) committee recommendation to evaluate use of compartments in the repository. In this way, use of MgO might be confined to regions that had low Pu inventories, thereby reducing the uncertainties associated with increased solubility of Pu in the presence of metastable MgO-carbonates.

On p. 62, EPA states "For undisturbed repository scenarios cellulose degradation products are unlikely to increase actinide concentrations in the aqueous phase." This statement is in direct conflict with the results of extensive studies in England that showed that Pu solubility was greatly increased by the presence of chemical degradation products of cellulose produced at high pH. See the references cited in the previous section (7) for details.

Section 9: "Conclusions and Key Issues"

This section summarizes positions discussed by EPA in sections 2-8. No specific comments are needed, since the issues have been addressed in the introductory General Comments and in the section-by-section comments above.

2.4 SPALLINGS

The blowout of spalled material reaching the accessible environment through an inadvertent human intrusion through a borehole into the WIPP repository could cause major problems with the compliance of the EPA's limit established in the 40 CFR Part 191 (U.S. EPA, 1996). EEG's Letter to F. Marcinowski, dated December 31, 1997 (Appendix 8.3) has shown that spalled volume, based on 100 realizations which have volumes ranging from 8 m^3 to 64 m^3 can violate these standards. However, the CCA and other DOE published results have shown that a blowout would purge less than 4.0 m^3 of waste from the repository, with 0.27 m^3 being a more typical volume (Hansen et al., 1997). Yet, none of the DOE models accurately calculate spall under varying repository conditions. For example, the main codes used to verify the reasonable volumes predicted in the CCA cannot be used under more appropriate waste permeabilities, gas viscosities, and mud drilling densities (from either mud brine or an underbalanced drilling fluid). The models also ignore potentially important failure mechanisms such as shear failure of waste under compression. It is EEG's belief that the issue has not been addressed fully to determine whether compliance with the containment requirements, 40 CFR Part 191.13 has been met. Therefore, it is recommended that EPA require DOE to develop a new model, which incorporates all the processes involved with spall. This is particularly important since spallings has the potential to returning more waste to the biosphere than any other human intrusion scenario.

2.4.1 Definition

Spall is waste that has been introduced into the drilling fluid due to radially channeled, highly pressurized gas flow from within the repository to a lower pressure borehole. Gas will continue to flow until the system comes to pressure equilibrium between the repository and the borehole. The high flow rates of gas will cause some of the waste material to fail in tension or shear, break off from the borehole cavity, and be introduced into the return stream of the drilling fluid. If gas flow is sufficiently high, it will force all the drilling fluid out of the borehole to the surface. This phenomenon is known as blowout, and is a common occurrence among drilling rigs encountering pressurized pockets of natural gas.

Spall can also occur by the mechanisms of stuck pipe and gas-induced erosion. These phenomena may dominate a spalled event if the gas flows are too low to cause blowout. Stuck pipe is a process of spall that, due to very low permeability and extremely high repository pressures, may cause failed waste to press against the drill string sufficiently hard to prevent normal drilling. The solution for a jammed bit is to pull the drill string up and start drilling again. If the pressures remain high, the driller may have to bring the bit up several times, thus allowing significant quantities of waste to be brought to the surface through the return stream of the drilling mud. Gas erosion is spall that is eroded by the drilling mud due to high repository pressures and low waste permeability. The spall from gas erosion is slower than stuck pipe due to slightly lower pressures in the repository (just above hydrostatic), and may release waste into the drilling mud at a rate undetectable by the driller. Gas erosion would continue until the repository pressure is in equilibrium with the drilling fluid, and may also bring significant quantities of waste to the surface.

When applying the terms of stuck pipe and gas erosion to the disposal system, slightly different definitions may be in order. Stuck pipe and gas erosion releases have been said to occur if the waste permeability is less than $1x10^{-16}$ m^2, as stated in Berglund (1994), and repository pressures are greater than the pressure exerted by the drilling mud (above hydrostatic). The CCA states that the waste permeability can be represented by a constant value of $1.7x10^{-13}$ m^2, which is much greater than the threshold for stuck pipe to occur. Additional studies show that waste surrogates based on current understanding of waste mixtures could have a permeability of $2.1x10^{-15}$ to $5.3x10^{-15}$ m^2 (Hansen et al., 1997), and that the threshold for blowout to cease and stuck pipe / gas erosion to begin is questionable (EEG letter dated Dec. 31, 1997 - Appendix 8.3).

The single representation of waste permeability by DOE was a necessity, based on flow model calculations of brine and gas through the repository in the two-phase flow code, BRAGFLO. The geometry of the disposal system in BRAGFLO only designated 21 cells for the waste area and many of these cells were on the order of 44 meters wide by 1.32 meters high. The spatial variability of the waste permeability could not be accurately implemented in these few large cells, and a constant homogeneous waste was more appropriate. When the scale of modeling reduces from the entire disposal system to repository room size, or even smaller (a few meters around a borehole intrusion), then the variations in waste permeability should also be on a smaller scale for the local conditions.

2.4.2 Calculation of Spallings

The DOE has calculated the amount of material that will spall through a blowout. The code CUTTINGS_S (U.S. DOE, 1996c-Appendix CUTTINGS_S) incorporates the spallings calculations with calculations of the amount of cuttings and cavings from a drill string drilling through the repository. The calculations showed that a maximum of 4.0 m^3 would spall in the borehole cavity and be transported out of the borehole to the surface. However, an independent peer review found the code to be conceptually flawed. The DOE's Conceptual Model Peer Review Group (U.S. DOE, 1996c-Appendix Peer 1) stated that the "Development of this [spallings] model is not sufficiently complete to determine uncertainties specific to the channel movement of waste to the existing borehole". The threshold for waste permeability and stuck pipe to occur was also based on the findings of this code.

The spallings volume was re-calculated by using a second code, GASOUT (Shatz, 1997), along with several other methods, to assess whether the results of the spalled material calculated in the CCA were reasonable. The GASOUT code was accepted by the Conceptual Model Peer Review Group (Wilson et al., 1997) based only on the conceptual model, without any independent testing or validation. Calculations with the GASOUT yielded a maximum of 0.27 m^3 to reach the accessible environment upon a breach (Hansen et al., 1997). The main assumptions used in the code to derive the calculated volume was a waste permeability of 1.7×10^{-13} m^2, a repository pressure of 14.8 MPa, and a waste tensile strength of 10 psi (0.068 MPa). Despite better understanding of the waste and measured values of the waste permeability, 4.0×10^{-15}, as described in Hansen et al. (1997), the CCA value of permeability (1.7×10^{-13}) was used for this investigation.

GASOUT uses a semi-analytic approach of a mechanistic conceptual model that couples the numerical calculations of a finite difference fluid flow code and a finite element rock mechanics code. This approach has been dubbed “the cavity growth method”, because it progressively calculates the region of radial tensile failure within the cavity. Hansen et al. (1997) showed that there is no tensile failure of waste below repository gas pressures of 14 MPa “under realistic but conservative assumptions”.

The conceptual model of the code during the blowout process was described as being divided into two stages. The first stage is characterized by the ejection of the drilling mud by high pressure gases, and the response of the waste to the high pressure gradients during blowout. Following the blowout, the second stage is identified by the rapid flow of gas from the repository, including the entrainment of solid waste particles. In the first stage of initial depressurization, gas velocities are small while the mud column is being expelled from the borehole. The velocities will increase during stage two, as the borehole path is clear for rapid gas movement. The larger eroded waste particles will typically be lofted to the surface during this stage. It must be noted that confidence in the GASOUT code can only be placed on the calculations during early times of the first stage. Late times of stage one would involve the decompression of the waste gas, which is not incoporated into the model.

In addition to the analysis using GASOUT, a “quasi-static” and “fully coupled” approach to solve the spallings problem was employed by DOE. The quasi-static used a spread sheet analysis to solve the porous flow equations by a sequence of steady state profiles (Hansen et al., 1997, pg. 3-24), and the conceptual model used in the quasi-static was identical to the cavity growth (GASOUT) method. The major difference in the two models is that the cavity within the quasi-static model does not increase with the calculation of tensile failed waste removal. The results from the GASOUT calculation without failed material removal (removal of failed material is a toggle switch that can be turned on and off in the code), show almost perfect agreement with the quasi-static results under identical initial assumptions. The differences in the two methods are established very early in the conceptual and mathematical model of the system. GASOUT assumes a transient pressure response in the flow calculations, whereas the quasi-static method assumes a series of steady state calculations. Steady state ignores some very important features of pressure flow with respect to time. Tensile failed material calculations for the quasi-static model showed a 1.17 m^3 of spall with initial pressure conditions of 14.7 MPa and tensile strength of 15 psi (inferred from effective stress calculations). The cavity growth model calculated an equivalent 0.07 m^3 of spall.

The fully coupled approach used a purely numerical code (as opposed to the semi-analytic approach in GASOUT) to calculate the flow of gas within the waste region to the intruded borehole. The mathematical model of the fully coupled approach assumes a one-way coupling of the two-phase pressure decay following an intrusion with a decoupled two-phase pressure response within the simulated waste region. The fluid flow and waste pressure response were solved by the code TOUGH28W with the poromechanical waste response of stress and strain invoked in the code SPECTROM-32.

Though the code did not explicitly calculate failure, it did calculate the effective stresses within the waste. From the results using SPECTROM-32, the normal effective stresses (tensile stresses) shows a semi-hemispherical distribution at very early times. If the initial assumptions are 14.8 MPa, and the waste failure criterion is 10 psi, then the code would indicate a brittle elastic failure radius of 0.8 m (Hansen et al., 1997-Figure 4..4-1.-9, time=0.001 s), or 2.1 m^3 uncompacted volume. The same figure shows a stress distribution extended out to one second, but without considering the possibility of waste removal. The removed waste would have a significant impact on the stresses in the cavity.

2.4.3 The EEG's Concerns on Spallings

2.4.3.1 Waste Permeability and the Stuck Pipe Scenario:

The permeability of waste in the WIPP repository and its effect on stuck pipe and gas erosion were not adequately addressed in the performance assessment calculations of the CCA and PAVT. The constant value of 1.7×10^{-13} m^2 used for waste permeability in the CCA was based on an investigation of waste materials by Luker, Thompson, and Butcher (1991) in which a single value, homogeneous waste was needed for code calculations with BRAGFLO. The calculation of the permeability assumed that 40% of the waste volume was comprised of combustibles (45% Material 1, 37% Material 2, 9% 1-inch metal parts, 9% dry Portland cement), 40% metals and glass (50% 1-inch metal parts, 50% magnetite), and 20% sludge (assumed to be ordinary Portland cement cured for 130 days). The mean values used for the separate waste types are 1.7×10^{-14} m^2, 5.0×10^{-14} m^2, and 1.2×10^{-16} m^2 for combustibles, metals, and sludges, respectively. The mean values as reported above inherently assume a range of permeability values, and these ranges can be seen in Table 2. Table 2 reports the minimum, median, and maximum from each waste type assumed in the calculation of the permeability value in the CCA as reported in Butcher (1990).

The calculation for the permeability assumed flow parallel to layers of waste. Each waste type was a separate layer in the drum, and the permeability was calculated by:

$$K_{eff} = \frac{1}{V} \sum_{i=1}^{3} V_i k_i \ ,$$

where V is the total volume, V_i is the volume of the i^{th} component and k_i is the permeability of the i^{th} component. The i^{th} component of k is represented by the median value from Table 1. The volumes of each type of material were also considered in calculating the effective permeability of a drum. For the CCA, 40% combustibles, 40% metals, and 20% sludges were assumed from an average waste drum volume (U.S. DOE, 1996c-Appendix Peer 5). These values also varied from the different drum samples, and from defense site. The Los Alamos National Laboratory volume (by percentage) of combustibles had an averaged value of 20, whereas the Savannah River Plant averaged 70 (Butcher, 1989-Table 2). These variances in volume could cause the expected value of 1.7×10^{-13} to decrease significantly.

A strict calculation of permeability can be a dual-edged sword. The assumption that flow will be parallel to the artificial layers in each drum may be conservative for the calculation of maximum

	Min	Med	Max
Combustibles (m^2)	2.00E-15	1.70E-14	2.00E-13
Metals (m^2)	4.00E-15	5.00E-13	1.20E-12
Sludge (m^2)	1.10E-17	1.20E-16	1.70E-16

Table 2. Permeability Values Used to Calculate Waste Permeability in the CCA.

flow of gas and brine in the repository, yet nonconservative when considering the damaging effects of stuck pipe (and / or gas erosion) from a lower permeability. A lower permeability can be calculated if flow is assumed to be perpendicular to the waste layers. In this assumption, the lowest permeability layer will contribute largely to an effective permeability of the waste. With a perpendicular flow assumption, the effective permeability could be as low as 5.9×10^{-16} m^2. Therefore, the parallel flow is arbitrary, and could be seen as a nonconservative calculation.

In addition to the variability in permeability, the conceptual model review of the CCA (U.S. DOE, 1996c-Appendix Peer 5) agreed that the ranges should be assigned constructed distributions, as opposed to the above mean permeability values, which were mean values of a uniform distribution. Therefore, the new mean values for combustibles, metals, and sludges were given as 5.9×10^{-14}, 5.5×10^{-13}, and 1.05×10^{-16}, resulting in a K_{eff} of 2.4×10^{-13} m^2. This value of permeability was used in the EPA's Performance Assessment Verification Test (PAVT), and was also recommended by the EEG (EEG Letter to F. Marcinowski on March 14, 1997 - Appendix 8.2 of this report) to be more conservative with respect to gas and brine flow in the repository.

To clarify the misunderstanding on apparent conflicting recommendations by the EEG on waste permeability on separate occasions, one must remember the context in which the recommendations were given. The March 14 letter to Frank Marcinowski recommended a value of 2.4×10^{-13} m^2 for the calculation of gas and brine flow within the repository. This value was 1) for use in BRAGFLO, where the spatial variability of heterogeneity is limited to a small number of grid cells and 2) made before the issuance of a new spallings model which showed that stuck pipe and gas erosion could become valid scenarios during a drill intrusion. Therefore, EEG's recommendation (Neill, 1997, Appendix 8.3) given to the EPA that the waste permeability should include variances in all models still remains valid.

Calculations of waste permeability from discrete layers of different waste material in the drums is inherently incorrect. In reality, the waste in the drums emplaced at the WIPP will be heterogeneously mixed, not in distinct layers, and the test specimens from Butcher (1990), and Luker et al. (1991) should have included a mixture of all waste types. A new set of permeability measurements from Hansen et al. (1997) report that the permeability of waste could be as low as $2.1x10^{-15}$ m^2 with a typical value of $4x10^{-15}$ m^2, using heterogeneously mixed waste. These specimens assume 63% metal (iron), 9.6% glass, 6.75% cellulosics, 11.6% crushed rock and cement, 4.8% soil, and 4.5% crushed salt. The permeability was conducted on a specimen containing most types of waste. It cannot be overly stressed that the measurements conducted in Hansen et al. (1997) are actual measurements on waste surrogates. The surrogates were constructed based on a deeper understanding of potentially degraded waste in future repository conditions and included waste forms of 50 and 100% degradation. The measured values are as much as two orders of magnitude lower than the calculated values used in the CCA. Again, calculated values should signal that the values are arbitrary, and do not account for variability in the waste.

In addition to the problems with the waste permeability on the use of measured vs. calculated values, it must also be stated that none of the permeability measurements were on samples that included MgO. The Particle Size Expert Elicitation Panel (U.S. DOE, 1997a) states that corrosion products, dissolved MgO and salt from brine that do not precipitate out as particulates will cement together. Cementation was a major contributor to the projected increase in waste strength to 77 Pa, and MgO is said to occupy 25.5% of the room volume after closure. The panel specifically defined the waste to mean waste plus backfill (U.S. DOE, 1997a).

The permeability of MgO as an additive to Portland cement has been studied by Zheng et al. (1991), and was found to have roughly the same permeability as Portland cement. They noted that higher percentages of MgO would result in higher permeabilities. It therefore follows that the permeability of cemented MgO is at the upper end of Portland cement, approximately $1.05x10^{-16}$ m^2 for sludges. In addition to lower permeability, the effects of MgO will increase waste strength in some localized areas. Permeability and strength are inversely correlated. Yet, if permeability and strength measurements taken on waste surrogate specimens with MgO are to be ignored based on conservatism, it must be remembered that the waste strength of specimens which varied between 5 to 15 psi in Hansen et al. (1997) also had permeability values on the order of $4x10^{-15}$ m^2. So, if a permeability, lower than that used in the CCA (and consequently in the

PAVT), is used in a model as more representative repository conditions measured values from Hansen et al. (1997), the waste tensile strength from the same report should also be used.

Keeping in mind that the values used in the calculations were median values from a range of possible permeabilities, the waste permeability could be lower. The median permeability ranged in the CCA from 10^{-12} to 10^{-16} m^2 (U.S. DOE, 1996c). Therefore, the single value of waste permeability used in the CCA does not fully represent the possible range of values that could exist in the repository.

Recommendations for Waste Permeability and Stuck Pipe:
Again, to clarify the EEG's position for waste permeability stated in the March 14, 1997 letter to EPA (Appendix 8.2), it seems as though two contradictory positions were taken. In the position statement on waste permeability used in the direct brine release calculation, EEG suggested a value of $2.4x10^{-13}$ m^2 be used instead of $1.7x10^{-13}$ m^2, "if a single value for consolidated waste permeability is to be used for direct brine release". In the position statement on the spallings model, EEG stated that the CCA reported an uncertainty range of 10^{-12} m^2 to 10^{-16} m^2 for compacted repository waste permeability. It is possible that precipitation of magnesium chloride cement and salt would reduce permeability below this range. The EEG recommended that "a more realistic value or range of values should be assumed for the waste permeability parameter and the potential for gas erosion and the stuck pipe processes be included in the spallings scenario with a better defined permeability-pressure threshold".

The spallings investigation documented in Hansen et al., (1997) contains results from permeability measurements of surrogate waste material that provide a much better basis for assigning waste permeability values. The permeability measurements do not include samples that contained magnesium chloride cement and, thus do not represent the lower bound of potential compacted waste permeability.

It is essential that the sensitivity of the Hansen et al., (1997) spallings model to waste permeability be investigated before the EPA can conclude that the spallings model used in the performance assessment is indeed conservative as stated in the proposed rule. Unless further additional measurements on surrogate waste that includes magnesium chloride cement are available, the range of 10^{-12} to 10^{-16} m^2 is a reasonable range to investigate the sensitivity of the spallings model to permeability variation. If it is found that the model predicts greater spall volumes in this range than calculated in the performance assessment then the measurements of surrogate waste with magnesium chloride cement should be conducted to define the range more closely.

Blowout is not the only mechanism for releases to the surface. Unless it can be shown that entrainment of spall into the drilling mud (gas erosion) or re-drilling by the operator (stuck pipe) will be limited, it should be assumed that all of the calculated spall material will reach the surface.

2.4.3.2 DOE’s Model Predictions of Spallings:

It is clear that the prediction of spalled material from the result of a borehole intrusion into the repository is difficult to quantify. The original model used in the CCA, developed by Berglund (1994), oversimplified the process, and therefore was judged as inadequate by the Conceptual Model’s Peer Review Panel (U.S. DOE, 1996c, Appendix Peer 1). However, the results of the model were defended as being reasonable for use in the CCA, by presenting additional models which showed lower spalled release upon an intrusion. Therefore, the spallings values calculated in the CCA were considered by the DOE to be the maximum reasonable values that could be brought to the surface during a breach.

The spallings’ volumes that were calculated in the CCA ranged from 0.5 m^3 to 4.0 m^3, and were subsequently used in the PAVT. The new prediction, with a more accurate set of models showed the maximum release to be 0.27 m^3. The new model used the lowest measured waste strength and the highest possible repository pressures that could be sustained for long time periods. At higher waste strengths and lower pressures, the analysis predicted much smaller volumes. However, EEG believes that the initial assumptions used in the models simulations do not accurately portray all repository conditions, and that under different circumstances the models can predict higher spalled volumes. EEG also believes that the models are inadequate to quantify the maximum possible releases due to limitations in the conceptual model development and code implementation. Therefore, the results presented in Hansen et al. (1997) are not actually maximum calculated releases, but only a set of calculated releases under certain repository conditions. The following discussion shows the limitations of the analyses presented in Hansen et al. (1997).

Three methods were used for the analysis of spallings in Hansen et al. (1997): 1) cavity growth method (implemented in the code GASOUT), 2) quasi-static method (implemented in two spread sheet files called P145APC4, and S145APC4), and 3) fully coupled method (used to existing codes, TOUGH28 and SPECTROM32). The results for comparison of the CCA volumes came from the cavity growth method, since this method was the most realistic, physically. The cavity growth allows for material removal during failure calculations, and hence the pore pressures are redistributed at the new boundary. The other two methods strictly calculate the effective stresses in the waste (the difference in the total stress of the overburden rock and pore pressure), and failure is interpolated. These other methods were used to verify the cavity growth model and are explained above in more detail.

The sensitivity of the GASOUT code was studied by EEG, in which permeability, viscosity, and mud density were examined over reasonable repository conditions. For example, the permeability could range between 10^{-12} and 10^{-16} m^2, but was restricted to 10^{-15} m^2 for this analysis. The viscosity of the repository gas could also vary, depending on which gases are produced. This next section presents highlights from a formal sensitivity analysis conducted by the EEG on GASOUT (Rucker, 1998).

Sensitivity to Permeability and Initial Repository Pressure

The GASOUT code was seen to be very insensitive to the initial permeability value chosen in this study. However, the code's use of a narrow range of values kept the sensitivity analysis to a minimum, and true sensitivity could not be established. The range of acceptable permeability values narrowed as the initial repository pressure increased, and waste tensile strength decreased.

Initially, the permeability used in the CCA of $1.7x10^{-13}$ m^2 was assumed in the present study to allow comparisons with the results in Hansen et al. (1997), despite a better understanding of permeability investigated in that report. The single value used in the CCA is under question, as it was calculated from assumed future waste conditions.

The results of spalled material failing in a borehole cavity using GASOUT over a wide range of permeabilities were not meaningful, and the code was simulated using a very narrow range. For the Base Case simulation for example, the waste permeability could only range from $0.8x10^{-13}$ to $4.4x10^{-13}$ m^2. Above and below these permeabilities, the code predicted extremely large failed volumes. The results of the failed volume versus the permeability range that was applicable for a five second simulation can be seen in Figure 3. The figure shows results of varying waste tensile strength, from 10 to 20 psi. The three curves represented in the figure give the upper and lower bounds of the permeability that result in meaningful values.

The reported failed volumes outside the range for the Base Case are extremely high, resulting in as much as 22.5 m^3 for a permeability of $0.5x10^{-13}$ m^2 due to the cascading affect of multiple zone failure. The geometry of the borehole cavity was discretized and solved on a hemispherical coordinate system. The layers of the hemisphere were kept to a minimum (0.01 meters) to avoid instability. When the waste in the borehole fails, it is assumed that the whole layer fails, and peels off like an onion skin. When the code calculates a large failed volume, as in the case with $0.5x10^{-13}$ m^2 permeability, the effect is several layers peeling off in one time step, cascading until an equilibrium is reached with the high pressure gradient that existed at a longer time period. It is assumed that when the cascading effect is exhibited, the results become meaningless.

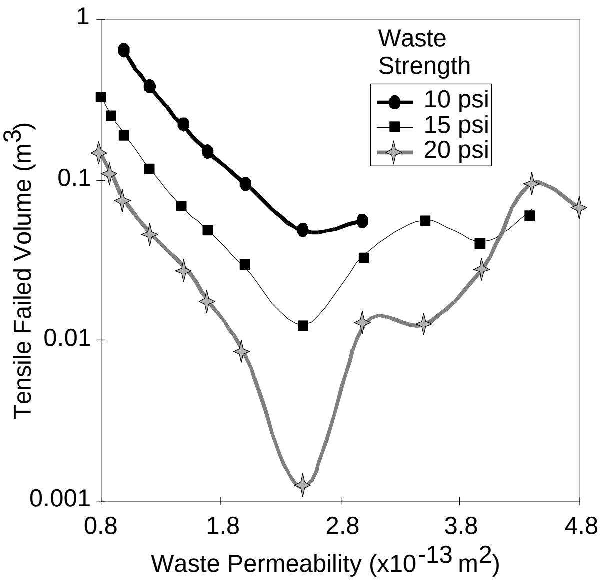

Figure 3. Contiguous Failed Volume as a Function of Increasing Waste Permeability for Different Waste Strengths With Initial Repository Pressure of 14.5 MPa.

Figure 3 shows some interesting results as the waste permeability increases. All the waste strengths tested showed an exponentially decreasing failed volume, up to a permeability of 2.5×10^{-13} m^2. Permeabilities above this value cause larger failed volumes than values below it. The upper limit on permeability shows that the code is reliable to 2.5×10^{-15} m^2 for waste strengths that were measured in the report by Hansen et al. (1997) and initial repository pressure of 14.5 MPa. The lower permeability limit is 1.0×10^{-13} m^2 for 10 psi waste strength, and decreases to 0.8×10^{-13} m^2 for waste strengths of 15 and 20 psi.

When the initial pressure is increased to its maximum of 14.8 MPa, the range is more narrow than discussed above. For all waste strengths investigated, confidence was only in waste permeabilities between 1.7×10^{-13} m^2 and 2.0×10^{-13} m^2. The narrow range that the code is applicable decreases the likelihood that the code can represent the disposal system accurately, and should be modified to allow more representative values to be modeled.

The simulation of the repository with a homogeneous waste in GASOUT is an over simplification of the repository model. It is much more likely that the waste permeability will actually be lower than that assumed in the CCA. The representation of a random permeability was explored in Hansen et al. (1997) using a fully coupled numerical code to solve the flow of gas through the repository. TOUGH28W did not calculate the amount of waste failure, but could calculate the pressure distribution through the waste for varying conditions. The code showed that a lower permeability, with values ranging from $1x10^{-12}$ to $1x10^{-16}$ m^2 would have a much higher pressure gradient near the borehole, than the permeability assumed in the CCA. It also showed that homogeneous waste with lower permeabilities will have higher pressure gradients. Higher gradient will produce lower total stresses of the overburden rock, and lower effective stresses in the waste. This further strengthens the argument for modifying GASOUT to represent the repository more accurately.

Sensitivity of Gas Viscosity

The gas viscosity parameter, along with porosity and permeability, is used to calculate the hydraulic conductivity of gas through porous media, K, by the relationship of

$$K = \frac{k}{2fm}$$

where k is permeability, ϕ is porosity, and μ is gas viscosity. The original equation for the flow of gas through porous media can be found in Chan et al. (1993) , and is equivalent to the non-linear diffusion equation. The viscosity of in the equation above is indirectly proportional to the gas conductivity, and as viscosity increases, conductivity decreases. The relationship also shows that a constant ratio of permeability to viscosity will yield the same conductivity.

The experiment with permeability demonstrated that values less than $1x10^{-13}$ m^2 for an initial pressure of 14.5 MPa would render the results meaningless. The viscosity used in the experiments was $10x10^{-6}$ Pa*s, and the ratio of permeability to viscosity yields $1x10^{-8}$. Values less than this ratio will cause the code to predict cascading failure of waste. If the original permeability is $1.7x10^{-13}$ m^2, then viscosity values greater than $17x10^{-6}$ Pa*s will cause the code to give erroneous results. The ratio for failure increases to $1.7x10^{-8}$ for initial repository pressure of 14.8 MPa and waste tensile strength of 10 psi. A simulation with the ratio of $1x10^{-8}$ m^2/Pa/s and for an initial pressure of 14.5 MPa and tensile waste strength of 10 psi yields a failed volume of 0.63 m^3.

The possibility of larger viscosity values is not ill conceived. The viscosity value obtained for ydrogen gas was the standard temperature and pressure value (STP), and viscosity will increase moderately as pressure or temperature increases.

The components of the repository gas will also increase the viscosity. Through microbial degradation of plastics, rubbers, and other combustible material in the repository, O_2, CO_2, CH_4, N_2, N_2O and H_2S will be created. Francis et al. (1997) conducted experiments of microbial gas generation under expected WIPP repository conditions and found that the percentage of N_2 varied between 61.9% to 91.4%, CO_2 varied between 0.4% and 34.3%, and H_2 varied between 0% and 12.8%. These other constituents have a much higher viscosity than H_2, with N_2 being as high as $19.2x10^{-6}$ Pa*s (STP), which will undoubtedly increase with an increased repository pressure.

Even though microbial degradation may create higher quantities of CO_2, and N_2 than H_2, the process itself will be limited. It is uncertain if the colonies of microbes will exist under repository conditions, and was assigned a 50% chance in the CCA.

Iron corrosion on the other hand will produce massive quantities of H_2 and it is certain that iron will corrode when brine fills the repository. Approximately $2x10^9$ moles of H_2 (Telander et al., 1996) will be produced from the iron in WIPP. However, the other gaseous constituents could play a small role if microbial degradation does produce gas. In Appendix MASS of the CCA, Figure MASS-1 (U.S. DOE, 1996c, Appendix MASS) shows that at lithostatic pressure, if the mole fraction of H_2 to CO_2 is reduced from 100% to 90%, then the viscosity would increase from $9x10^{-6}$ Pa*s to $16x10^{-6}$ Pa*s. Therefore, it is suggested that the code be modified to allow a larger spectrum of values to be modeled.

Sensitivity to Mud Column Density

The density of the mud column in the borehole is dependent on the type of drilling mud used. For the WIPP, it is most likely that the drilling mud will come from the Salado Formation with additives to increase the average mud density to 10 - 11 lb/gal (1200-1320 kg/m^3). The GASOUT code used a density of 1249.3 kg/m^3 in the Hansen Investigation, and it is possible that this value could vary over the range mentioned above.

Figure 4 shows the results of varying the parameter from 1200 to 1320 kg/m^3 for a 10 second simulation and an initial repository pressure of 14.8 MPa. The figure shows three curves of different waste strength, with all other parameters remaining the same as used in the Base Case simulation. The most outstanding feature of Figure 4 is the disjointed curve of failed waste (left) and mud motion (right) of the 10 psi tensile waste strength simulation. The code had trouble calculating failed waste for mud densities below 1228 kg/m^3, resulting in the cascading affect described above. The code also had trouble at 1240 and 1250 kg/m^3, and if results were plotted for these densities (failed waste and mud motion), sharp spikes would exist in the curve.

For the higher waste strengths (and subsequently lower repository pressures) of 15 and 20 psi, the mud density simulations were able to calculate failed volumes for all density values investigated. However, the results seemed almost as unreliable as the lower waste strength. Though a trend can be seen in the failed volume and mud motion, variances from those trends are high. Both graphs in Figure 4. show trouble with densities between 1230 to 1270 kg/m^3.

Sensitivity to Waste Porosity

Lastly, the code was investigated to test the effect of waste failure with decreasing porosity. If the porosity is lower, then the velocity of the gas moving through the repository to a borehole intrusion is higher. The report by Hansen and coworkers report a porosity of 0.7, which was said to be typical of waste porosity when the pressure reached over 14.8 MPa. However, after investigating the relationship between pressure and porosity, it was found that porosity during the long-term performance of the repository was approximately 0.4 for high pressures, and less for lower pressures. Figure 5 shows the relationship of porosity to pressure for the

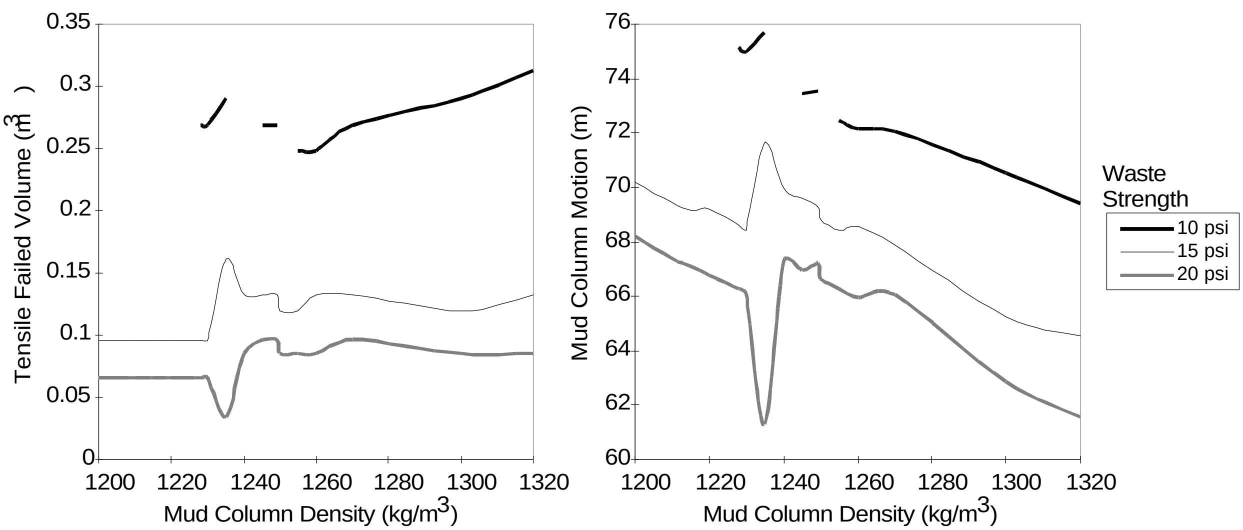

Figure 4. Left) Tensile Failed Volume as a Function of Mud Column Density for Several Waste Strengths. Right) Mud Column Motion as a Function of Mud Column Density. The Discontinuous Curve for the Low Waste Strength of 10 psi Indicates Cascading of Failed Waste at the Values Chosen for the Experiment.

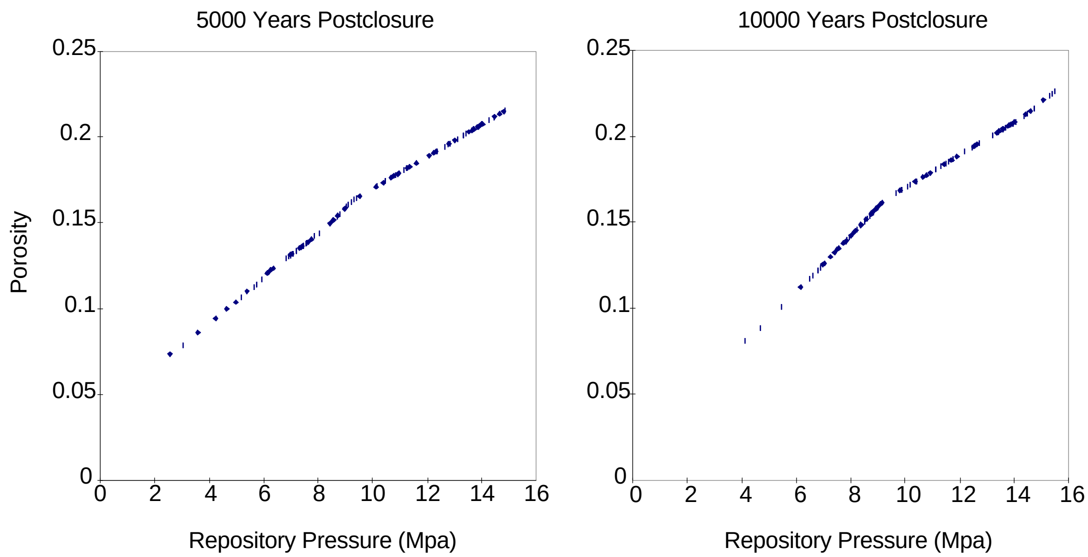

Figure 5. BRAGFLO Porosity Values Versus Pressure Profiles for Undisturbed Scenarios of the CCA.

undisturbed scenario of the performance assessment for the CCA. The figure shows two separate times, at 5000 and 10000 years postclosure using the results of BRAGFLO. The figure reports porosities assuming no compaction of the waste form from consolidation of halite creep. If the room is assumed to shrink by half, then the porosities would double. On this assumption, the actual waste porosities in the repository would be double that of the figure for a given pressure.

Porosity from the two-phase calculations of brine and gas flow through the repository clearly will be lower than anticipated in GASOUT. The response of the code to lower repository porosities shows slightly higher releases. For an extremely low porosity of 0.2, with initial conditions of 14.8 MPa repository pressure, and 10 psi waste strength, the uncompacted spalled volume is 0.47 m^3, and decreases smoothly up to the original porosity of 0.7 and a calculated failed volume of 0.27 m^3. However, porosities above 0.7 and below 0.2 cause the waste to cascade, and results are interpreted as numerical artifacts. Additional experiments using a variety of repository pressures and their expected porosities from Figure 5, does not show any further problems within the code.

-end

In addition to the cavity growth experiments with GASOUT, the option of failed material removal was “turned off”, and the affects of decreased permeability was studied again. The surprise result of this new set of calculations shows that the effective stresses in the waste are significantly high to cause radial failure beyond the assumed 0.27 m^3, as presented in Hansen et al. (1997). Figure 6 shows an analogous model for permeability assuming both with and without material failure. The left plot of the figure shows a common scenario with initial repository pressures at 14.5 MPa, permeability equal to 1.7×10^{-13} m^2 and the results from GASOUT with both options of material failure. It shows that material removal produces higher failed volumes than calculations without material removal. The right plot, again with 14.5 MPa initial repository pressure, shows results of GASOUT without material removal for two permeability values. The option for material removal was turned off due to the observations of the above sensitivity analysis. The set of curves on the right-hand-side shows that lower waste permeability produces higher volumes. It therefore can be deduced that if low permeability and waste failure removal calculations are initiated, then the volumes of failed material may be even greater than seen on either plot of Figure 6 It is unknown the exact extent to which material failure will increase. It is plausible that system could attain equilibrium quicker, and the differences are insignificant

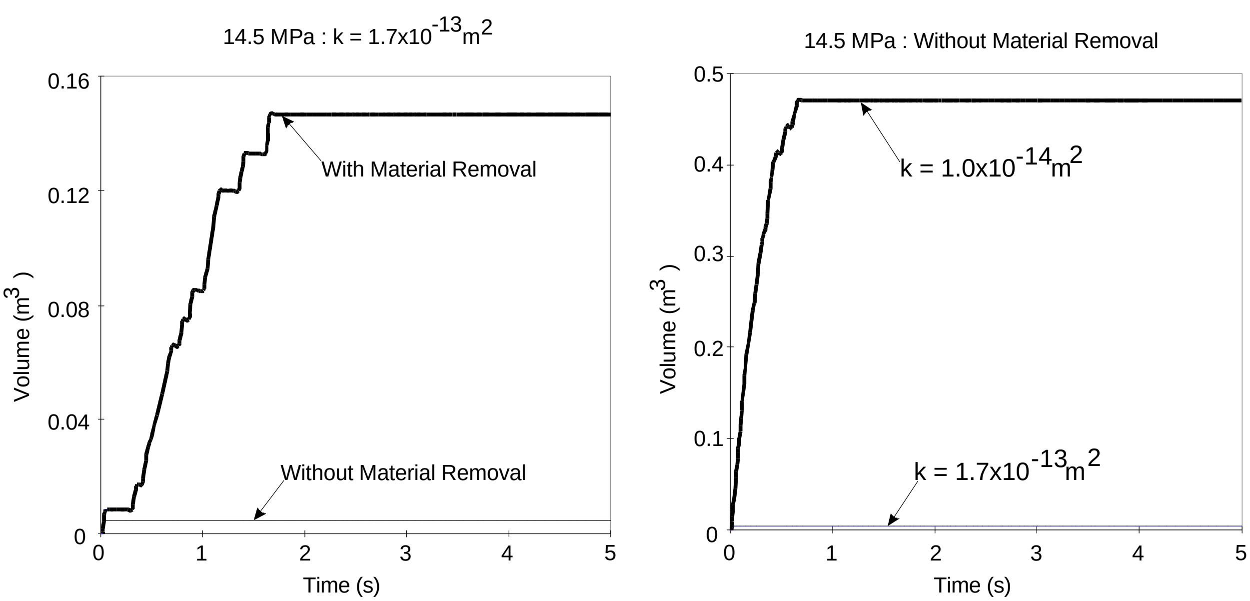

Figure 6. GASOUT Analogy Illustrating The Importance Of Considering Lower Permeabilities. Left) Constant Permeability With And Without Material Removal. Right) Without Material Removal At Two Different Permeabilities.

For an extreme example of the above analogy, Figure 7 shows radial distance of potential failure at permeabilities of 1.7×10^{-13} and 1×10^{-14} m^2 for pressures at 14.8 MPa without material removal. Potential failure was extrapolated from the effective stresses that would exist in non-failed material. The repository pressure was set at 14.8 MPa and waste strength at 10 psi for the experiments in Figure 7.

The figure clearly shows that when permeability is lower than assumed in the CCA then releases will be higher than assumed from the investigation in Hansen et al. (1997). The maximum radial failure at a permeability of 1×10^{-14} m^2 is 1.17 m, equating to an uncompacted spalled volume of 6.6 m^3. It is believed that when permeability is even lower than the lowest value presented in Figure 7, the releases could be higher. However, the code has difficulties with oscillations in pressures at lower permeabilities, and confidence in results is low.

The results of Figure 7 must be kept in context. When material is not removed during the pore pressure calculations (and subsequently total overburden stress), the code does not redistribute values at the new boundary. Instead, the pore pressures decrease in that region, hence lowering the possibility of new failed material. Therefore, Figure 7 actually underestimates the potential effect of failure, and higher volumes will result if the material is removed. These calculations are not possible with GASOUT, with reasons explained from the sensitivity analysis with the code.

Lastly, the issue of shear failure of waste has been eliminated from spall calculations in Hansen et al. (1997) due to its suspected low consequence on overall spall releases. The report by Dr. Frank Hansen and group state that material that fails in shear will not necessarily fragment, and that the region of shear failure is generally less than or equal to the region of tensile failure. The response to the first half of the statement on fragmentation suggests a large degree of uncertainty. The waste will have a residual shear strength component remaining after failure if it does not fragment. Since the nature of the waste already has such a low compressive strength, residual strength after failure will be nominal at best (assuming inelasticity). An average value of 0.75 MPa for shear strength was measured with partially saturated waste surrogates and partially degraded waste forms. After failure, it is assumed that the stresses needed to deform the waste is

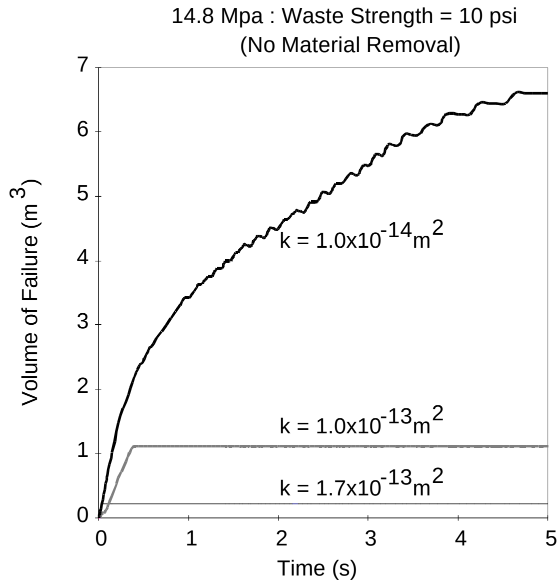

Figure 7. Failure Volume (m^3) vs Time (s) for Different Waste Permeabilities. The results are from GASOUT with the option of 'failed material removal' turned off.

much less, and that the simple act of erosion from the circulating drilling fluid would cause the material to fragment. Therefore, it is conservative to assume that waste failed in shear is totally fragmented.

Considering the region of shear failure, there are some circumstances in which it would be larger than the tensile failed region. Figure 8 shows a calculation by GASOUT without material removal for a typical case of 14.5 MPa repository pressure and permeability of $1.7\text{x}10^{-13}$ m^2. The left plot shows the normal effective stresses in the waste with the tensile strength (dotted line) and the right plot shows shear effective stresses with maximum shear strength. The figure on the left demonstrates that the tensile failed radius will be approximately 0.17 m. The initial borehole radius is 0.1556 m, giving rise to a mere 0.005 m^3 hemispherical volume of failure region. On the right of Figure 8, the shear radius of failure after 5 seconds of simulation shows a value of 0.29 m, equivalent to a hemispherical volume of 0.09 m^3. Though the failed volumes are very slight and may seem inconsequential, the region of shear precedes the region of tensile failure. Furthermore, it is observed that shear failure is an important mechanisms for failure when seepage gradients through the waste are small. For example, when the initial pressure is lowered to 12.0 MPa, no

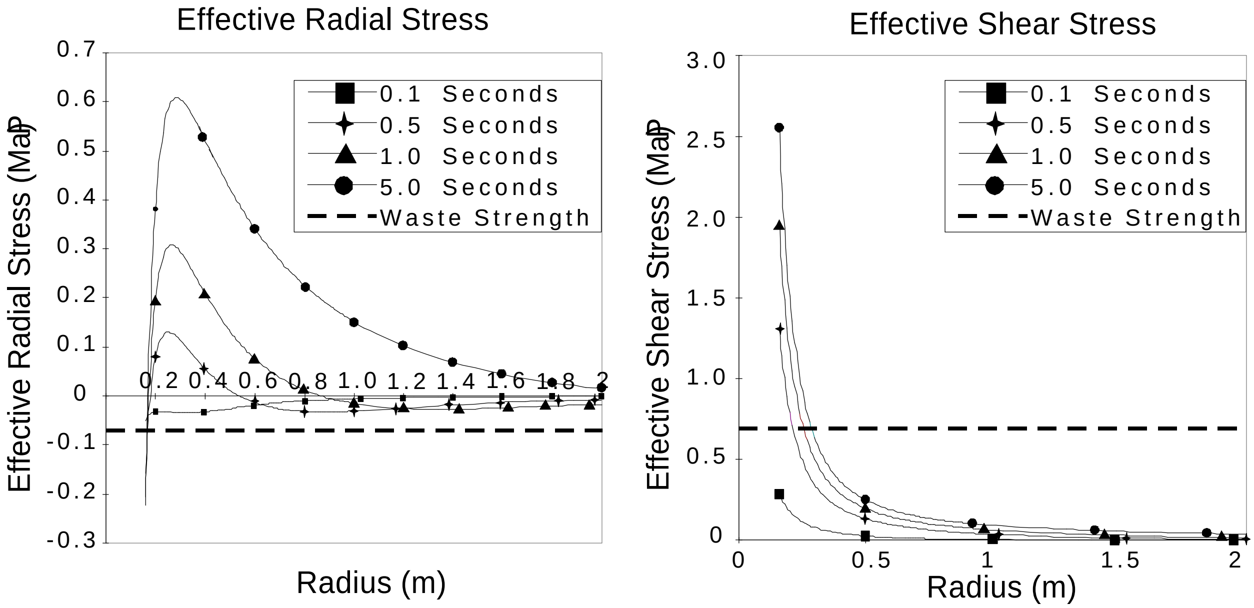

Figure 8. Computed Radial (Normal) And Shear Stresses In A Hemispherical Cavity During Spall From GASOUT, Assuming 14.5 MPa Initial Repository Pressure, 1.7×10^{-13} m^2 Waste Permeability, And No Material Removal From Failure.

tensile failure is observed. Yet, the effective shear stresses in the waste are noticed to increase, and failure for the experiment is seen to occur at approximately 0.3 m from the borehole center. The experiments assume no failed material removal, and it is conceivable that the extent of failure could extend beyond these values. The opposite phenomena is observed when the seepage gradient is high; tensile failure precedes shear failure.

Recommendations for Models:

It is shown that the GASOUT code responds erratically to small changes in the input assumptions, and sometimes gives misleading results. GASOUT was the main code examined, due to its ability to remove material during failure, and for being the major code of spallings verifications for CCA values. EEG recommends that the code be examined more closely, before judging the results of Hansen et al. (1997) as the maximum amount of failed material that will reach the surface, and the spalled volumes calculated in the CCA as reasonable.

It is also recommended that a new spallings code be developed, that incorporates all the aspects of failure correctly. The GASOUT code seems to have difficulty with redistributing the pore pressures once waste has been removed. Also, the code only addressed the concern of tensile failure. In a hemispherical geometry, tangential forces will cause the material to be in compression, and the material could fail in shear. The GASOUT ignores shear failure as a possible mode of failure, although it is calculated. The strength of the waste is nominal in compression (measured values in Hansen et al., (1997) show a typical value of approximately 100 psi), and the pressures exerted from the overburden rock could cause the material to yield.

2.4.3.3 EPA's Model Prediction of Spallings

The EPA funded a separate investigation of the spallings phenomena that focused on potential limits on spall material reaching the surface because of insufficient lofting capacity of gases vented from the repository. The investigation is described in two reports (U.S. EPA, 1997e and 1997f). The first report assumes that spall occurs prior to penetration of the drill into the repository. It also assumes that the volume of material removed by the spallings process can be ignored. The second report assumes a one to two foot penetration of the drill string into the repository concurrent with formation of a spall cavity. The EPA investigation determined that venting of the repository would not be energetic enough to bring spall material to the surface. The conclusion is valid for evaluating the CCA spallings model but can't be extended to the most recent DOE spallings model. The investigation's focus is on relatively long term transport capability consistent with the CCA spallings model, not immediate transport of material from the formation of an explosive spall cavity, as in the most recent model.

The main emphasis of the EPA investigation is to explore whether there will be sufficient gas velocities in the repository-borehole system to transport particles, created by the spall process, to the surface. The ability of gas to entrain solid material is well understood. Vertical entrainment of larger particles requires greater gas velocities than smaller particles. The calculations predicted the maximum sized particle that could be transported to the surface by comparing calculated velocities to an established relationship of maximum size of entrained particles to hydrogen gas velocity. Three regions were examined to determine the most stringent limit on the size of transported particles. The smallest calculated velocities occurred in assumed void space created by the spall process. Applying the maximum particle size estimate to these velocities results in a prediction of 70 microns as the largest size particle that could be brought to the surface. 70

microns is smaller than the lower limit of particle distribution determined by the “particle size” expert elicitation panel. This leads the EPA investigators to conclude that spallings is a self-limiting process because of the inability of lofting new spall material from the cavity.

The spallings model used in the CCA performance assessment assumed that erosion of waste material would form channels in the repository room. The erosion process could last for days. The EPA investigation adopted an 11 day-long time frame and assumed that the first few seconds were not significant. This allows the adoption of cylindrical , one dimensional, radial flow approximation of flow through the repository to a borehole. The approximation is accurate only when pressure depletion extends far enough into the repository that a region, a few repository thicknesses in size, has a fully developed gradient. A fully developed gradient means, roughly, that little of the flow in the region is derived from local depressurization. Once the fully developed gradient forms, a pseudo skin factor is required to correct the one dimensional model for the two dimensional flow pattern near the borehole. The pseudo skin factor accounts for the fact that the drill was assumed to penetrate the repository only a few feet. The skin factor is applied as a permeability reduction of the repository waste near the borehole. This factor is 0.075 for a one foot penetration and 0.16 for a two foot penetration distance ($2.x10^{-5}$ with no penetration).

Both EPA reports are superceded, however, by the spallings model presented in January 1997 to the conceptual model peer review panel (Hansen et al., 1997). This model predicts that almost all spall would come from the face of the drilling cavity. The spall process would occur in the first few seconds of repository depressurization.

The permeability reduction used in the EPA model is inappropriate to address removal of the initial spall material. The spallings model of Hansen et al. (1997) predicts spalling will stop after a few seconds and that depressurization is negligible beyond roughly 1.5 meters at this time. Figure 5..6 of Hansen et al. (1997) presents the calculated pressure in the repository as a function of distance and time in the region of the borehole. During this initial depressurization the source of flow is from the region close to the borehole. It is this local depressurization that would cause spalling to progress away from the drilling bit.

The temporal and spatial discretization of the EPA investigation is far too coarse to investigate the potential for evacuation up the borehole of spall material created in the first few seconds. For example, in the case of a two foot penetration with 0.25 m^3 spall cavity, the first element of the EPA analysis is 0.39 m thick. In the Hansen et al. (1997) model, the first element is 0.01 m thick. In the EPA investigation the first time step is 86 seconds compared to 0.001 seconds in the Hansen et al. (1997) model. These differences in both temporal and spatial discretization are an indication that the EPA modeling can not predict gas velocities from local depressurization reliably. Hence, the two EPA reports can't be used to judge the conservatism of the spall model described in Hansen et al. (1997), nor the extension of the Hansen et al. (1997) model to potential spall from air drilling.

Hansen et al. (1997) also considered the issue of maximum particle size that could be transported up the borehole. Figure 6-22 of Hansen et al. (1997) indicates that particles as large as 10,000 microns may be transported to the surface after the mud column has been expelled from the borehole, about 250 seconds after intrusion, and that transport of such large particles could occur for much more than 200 seconds. Two-hundred and fifty seconds is still very early in the EPA investigation (3 time steps). The discritization of the EPA model is too coarse to accurately calculate the flow rates this early in the 11-day period.

The calculated mass flow rate of gas up the borehole does not increase at 250 seconds, in the Hansen et al. (1997) model. Instead, the carrying capacity of the gas jumps because of lower pressure in the borehole due to the removal of the mud column. This confirms the appropriateness of neglecting the mud column in the EPA investigation.

A less important criticism of the EPA investigation is the reliance on velocities calculated in the spall cavity. The velocities are calculated by dividing the flow up the borehole by the area of the entire cavity as if all the flow was vertical. Gas velocities in this region are not spatially constant and not vertical. Simple mass conservation implies that the velocities must be greater near the drill collar. In addition, particles need not be lofted in this region to be transported, except right at the borehole where the cavity velocities are greatest. Particles may be transported towards the borehole by both collapse of the spall material into the cavity and the drag of the radial velocities of the gas moving toward the drill collar annulus, even if the velocities are too weak to loft the particles. Horizontal transport by gas is known as saltation and should be recognizable to people who have witnessed an aluminum can being bounced along a roadway by the wind. In the case of the can, the wind velocity is rarely large enough to loft the can but the can bounces off the ground as it moves. The blowout experiments conducted for DOE (Lemke et al., 1996) demonstrated that, for material without cohesive strength, particles will be moved radially toward the gas vent. These experiments indicated that the cavity formed by material carried out the vent is filled by material being transported toward the vent along the upper surface of the cohesion-less mass of particles.

For consideration of removal of spall created in the first few seconds of a drilling intrusion into the repository, the calculations of Hansen et al. (1997) are more accurate than those of the EPA investigation because of the use of a one-dimensional cylindrical geometry and coarse discritization in the EPA model. The EPA investigation underestimates velocities during a spallings event. Based on the information supplied by Hansen et al. (1997), large enough gas velocities are likely to occur during a spallings event, for a long enough period, to transport large amounts of the spall material up the borehole. In conclusion, the calculations of Hansen et al. (1997) indicate that transport of spall material up the borehole will <u>not</u> limit the release of spall material to the surface.

2.5. AIR DRILLING

This section is to address the concerns of the EEG on the issue of EPA's Analysis of Air Drilling at WIPP (U.S. EPA, 1998). Based on its own analysis of Air Drilling in the Delaware Basin of New Mexico, the EPA has concluded that the air drilling scenario did not have to be considered in the DOE's Compliance Certification Application.

Dr. John Bredehoeft first proposed air drilling as a plausible scenario at WIPP in 1997 and conducted a modeling experiment (Bredehoeft, 1997a) to quantify the amount of spalled material that would be brought to the surface if the repository was inadvertently breached by a drill intrusion, using air as the drilling fluid. Drilling with air results in lower hydrostatic pressures in the bottom of the borehole, thus the possibility of higher pressure- gradients through the waste repository. Bredehoeft used the code GASOUT for his modeling, admitting that the code was not written for this purpose, but if used with caution, could yield approximate results. Bredehoeft concluded that air drilling could potentially violate the containment requirements of 40 CFR Part 191.13.

The DOE disputed Bredehoeft's modeling analysis, based on incorrect usage of the code. DOE argued that the code was designed for drilling with an incompressible fluid, and for low seepage gradients. When the code was used in Bredehoeft's study, it produced large amounts of waste failure, which were on the order of 500 - 2000 m^3. These high volumes were easily explained, argued DOE, and that the results were highly unlikely to occur at WIPP.

Further analysis by the EEG, which investigated the amount of brine that could be released through an air drilling event, also concluded that large amounts of radionuclides could be brought to the surface. The EEG estimated that the maximum amount of brine that could be blown out of the repository would be approximately 2000 m^3. However, the DOE showed that the EEG analysis contained conceptual errors and the EEG accepted the DOE's criticism.

Finally, the EPA conducted its own analysis and concluded that air drilling scenario of release is not valid on the basis of both low probability and low consequence. The following two sections respond to the EPA invitation for comments on the EPA analysis.

2.5.1 EEG's Critique of EPA's Air Drilling Analysis

The WIPP is located in a resource rich area and the EPA Standards for the disposal of transuranic waste require that the DOE application address inadvertent human intrusion. However, the DOE Compliance Certification Application did not address the issue of air drilling. In calculating the impact of resource exploitation on the cumulative release of radionuclides from the repository, the CCA performance assessment calculations addressed only the actual drilling event and only drilling methods which use brine as the drilling fluid.

In a report titled *Air Drilling into WIPP*, Bredehoeft (1997a) makes a compelling argument that the application needs to consider other known drilling technologies, such as the use of air rather than brine for the drilling fluid. The repository performance must be determined for the next 10,000 years and Bredehoeft notes that technologies, such as drilling, have changed in the past and will probably change in the future. He suggests that EPA required the DOE to treat the historical drilling rate as representative of the full 10,000 years to accommodate changes in drilling technology and mineral economics including minerals not currently in demand (Bredehoeft, 1997a, p. 1). Indeed, the preamble to the EPA Criteria states:

> In effect, when used for the purpose of determining the future drilling rate, today's drilling activities act as surrogates for the unknown resources that will be drilled for in the future (U.S. EPA 1996, p. 5233).

It is not clear that EPA's assumption of a constant drilling rate was intended to compensate for future changes in technology. Nonetheless, Bredehoeft identifies a problem that needs to be addressed. Bredehoeft attempts to prove, with a known drilling technology, that the assumption of a constant drilling rate for 10,000 years is not adequate to accommodate technological changes and he calculates the release of radionuclides from the repository as the result of a drilling intrusion. His calculations show a much larger release of radionuclides to the surface as a result of using air rather than brine for the drilling fluid.

2.5.1.1 Scenario Rejected by DOE and EPA on Basis of EPA Regulation

While Bredehoeft is proposing that an air drilling scenario be considered both, U.S. DOE (1998) and U.S. EPA (1998) have reiterated the position that the air drilling scenario can be ruled out on the basis of regulation. Within the confines of considering only the actual drilling event, the EPA Criteria specify a future state assumption for which:

> Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that: 1) future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include, but shall not be limited to: the types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans (U.S. EPA, 1996, §194.33(c)(1)).

On October 29, 1996, the DOE submitted the Compliance Certification Application. Appendix DEL states:

> There are a variety of drilling fluids used in Delaware Basin drilling. Most rotary drilling operations use saturated brine (10 to 10.5 pounds per gallon) as a drilling fluid until reaching the Bell Canyon Formation, where intermediate casing is set. (U.S. DOE, 1996c, p. DEL-32).

Hence, the CCA calculations are based on the assumption that all future drilling through the Salado Formation will be done with brine as the drilling fluid and drilling with any other fluid can be ruled out citing regulatory considerations.

The NEA/IAEA International Review Group (IRG) expressed its reservations about scenarios rejected on the basis of regulatory consideration in the absence of logical or physical arguments for such a scenario rejection (NEA/IAEA, 1997, p. 19). This appears to be an obvious shortcoming.

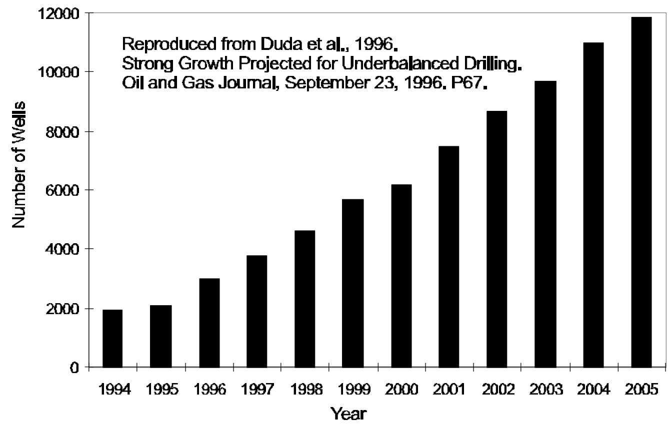

Fig. 9. DOE's projected use of underbalanced drilling in the United States.

Bredehoeft did not limit his consideration of scenarios to a choice of drilling fluid. He observes that air drilling is a proven technology and its frequency of use by the oil and gas industry is increasing as shown in Figure 9. An examination of published materials shows that use of underbalanced drilling, including air drilling, is expanding in the oil and gas industry with the explicit support of the DOE Office of Fossil Energy (Duda et al, 1996) and strongly suggests that the analyses may need to include other methods of underbalanced drilling, including foam, mist, dust, aerated mud and light weight solid additives.

2.5.1.2 Entire Delaware Basin not included in DOE and EPA Review of Records

U.S. DOE (1998) and U.S. EPA (1998) maintain that the drilling fluid used in the PA calculations is limited to current practice in the Delaware Basin which does not include air drilling. They do note a few exceptions in previous years and the more recent use of air drilling on one occasion to address a lost circulation problem.

With respect to current and historical practices, the DOE examined records on file with the New Mexico Oil Conservation Division (U.S. DOE, 1998, p. 5-12). The EPA examined 203 randomly selected drilling records from the NMOCD files for Eddy County and Lea County (U.S. EPA, 1998). The DOE and EPA each conclude, from information in the New Mexico records, that air drilling has rarely been used in the Delaware Basin.

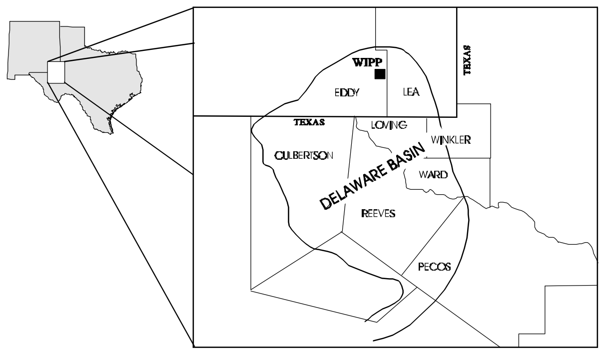

Fig 10. New Mexico and Texas Counties in the Delaware Basin

While, the EPA Criteria requires consideration of practices in the entire Delaware Basin, neither agency reviewed the Texas records although a large portion of the Delaware Basin is located in Texas. EPA documents a conversation with Mark Henkhaus, District Manager of the Texas Railroad Commission in Midland, Texas who indicated that Burlington Resources has done air drilling in Reeves and Pecos Counties, Texas. Although not noted in the EPA document, Reeves County, Texas lies entirely within the Delaware Basin. Compliance with the EPA Criteria requires examination of the appropriate Texas records as well as the appropriate New Mexico records.

2.5.1.3 Potential Inadequacy of Public Records

The EPA survey of drillers, consultants, and state employees found:

> None of the individuals contacted were aware of any oil industry related wells drilled within 20 miles of the WIPP Site using air technology ***for any purpose*** [emphasis added]. In addition, New Mexico Oil Conservation Division (NMOCD) regulatory personnel in Hobbs and Artesia indicated that no wells have been drilled from the ground surface with air in the New Mexico portion of the Delaware Basin because of

> the problems cited above (U.S. EPA, 1998, p. 13).

While the EPA survey did not find a single instance of oil field air drilling within 20 miles, EPA noted (U.S. EPA, 1998, p. 6) that the DOE found some evidence of a well having been partially drilled with air about 8 miles east-northeast of the WIPP Site Boundary. DOE stated:

> The information in the NMOCD and BLM records do not show evidence of air drilling at the Lincoln Federal #1. All information presented below was obtained verbally from representatives at Collins & Ware, Inc., the operator, and McVay Drilling, the driller of the well (U.S. DOE, 1998, p. 7).

The EPA also could not find any direct information documenting the use of air drilling. The use of air drilling was inferred from "statements in the well files that indicate that air was circulated while casing was set to the top of the Delaware Basin" (U.S. EPA, 1998, p. 6).

Neither DOE nor EPA could find documentation in the public record directly stating that this well was partially drilled with air. This raises a very important question about the reliability of the New Mexico records to document air drilling. If air drilling was indeed used in this well and that information is not stated in the public record, how many other wells have been drilled with air (foam, mist, aerated mud, or other underbalanced methods) without documentation? No conclusion can be drawn about the documentation in the Texas records for the Delaware Basin because apparently that search does not appear to have been conducted.

The DOE also conducted a survey of thirty drilling companies. Six were no longer in business, four had been acquired (by companies that did respond to the survey), and five could not be contacted. Fifteen companies responded. It was fortuitous that the company that drilled the Lincoln Federal #1 well was still in business and that the staff responding to the U.S. DOE (1998) inquiry remembered the use of air drilling for this very unusual well.

Although there were no direct statements on file in the public record, there is no question that this well was partially drilled with air. Page four of the actual drilling record clearly states:

4/11/91: Day -10

Drilling at 2620', made 735' in 19 1/2 hours. Formation Anhydrite and salt. MW 10, Vis 28, Ph 8. Bit #3 12 1/4" HTC, R-1, Jets 3/13's, in at 852', out at 2320', made 1468' in 39 1/4 hours, WOB 15-20,000, RPM 70. Bit #4 12 1/4" HTC, J-33L, Jets 3/13, in at 2320', made 300' in 7 hours, WOB 30,000, RPM 70. Pump #1 SPM 70, GPM 237, PP 700. Deviation survey at 1945' 1/2º, at 2320' 3/4º.
TIME BREAKDOWN: 2 hours drilling, 1 hour circulate out air pocket and water flow, 1 1/2 hours drilling with water flow, 1/2 hour survey, 9 hours drilling with partial returns, 3 hours trip for new bit and survey, 7 hours drilling with no returns. Hauled 8 loads of formation water to disposal. <u>Will continue to dry drill until air compressors on location and set up to air drill</u>. [Emphasis added].

4/12/91: Day -11

Drilling at 2984', made 364' in 9 hours. Formation salt and anhydrite. MW brine water. Bit #4 12 1/4" HTC, J-33C, jets 3/13, in at 2320', made 664' in 16 hours, WOB 20-30,000, RPM 76. Pump #1 SPM 90, PP 1100-600 psig. Deviation survey at 2667' 1 1/4º, at 2915' 1 3/4º.
TIME BREAKDOWN: 2 1/2 hours drilling with no returns, 1/2 hour deviation survey, I hour drilling, 1/2 hour pull 20 stands, 5 hours wait on brine, 1/2 hour trip out of the hole, 4 3/4 hours nipple up rotating head, change flowline and hook up compressors, 1 3/4 hours trip in hole, 1/2 hour install rotating head, 1/2 hour establish circulation, <u>3/4 hour air drilling</u>, 1/2 hour repair flowline, <u>4 1/4 hours air drilling</u>, 1/2 hour totco, <u>1/2 hour air drilling</u>.

Air drilling was used to overcome a lost circulation problem. However, the use of air drilling was not documented in the public record, which raises the concern that there could be other wells that were either fully or partially air drilled without public documentation.

The EPA and DOE report the use of air drilling in areas outside the Delaware Basin, based on discussions with various drillers. Could that information have been discerned from the available public record? There is no indication that either DOE or EPA verified that information obtained from drillers is also contained in the public record.

2.5.1.4 Water Influx

Based on a survey of drillers, the DOE maintains that the potential influx of water is a deterrent to drilling with air. U.S. EPA's (1998) industry survey also found that large water inflow was the most commonly cited reason why air drilling is not conducted in the Delaware Basin, including the area around the WIPP Site. But as noted in the EPA survey of drillers, "air drilling technology is improving at a relatively rapid pace and new larger rigs are capable of handling more water influx than in the past" (U.S. EPA, 1998, p. 9). EPA acknowledges that air drilling technology is capable of handling higher water inflows by using larger air compressors (U.S. EPA, 1998, p. 15) which is consistent with the observation that "new equipment is available" (U.S. EPA, 1998, p. 9). Furthermore, the DOE and industry are also optimistic about the potential market for light-weight fluids not adversely affected by the invasion of other fluids and the use of light weight solid additives to overcome contamination problems associated with fluid influxes (Duda et al.,1996, p. 76) .

The drilling report for the Lincoln Federal #1 includes the following important notation, at the bottom of page four, indicating air drilling moved large volumes of water from 2000 feet up to the zone of lost circulation and the remaining water up to the surface pit.

> **NOTE: Both Air and Brine are being pumped; pit gain with air on hole; pit loss without. We are drilling with air until pits fill up, then dry drilling using brine water that is in the pits. When pits get low we go back to air drilling.

The actual drilling record was used to prepare the following account:

> On April 2, 1991, drilling was initiated for a gas well on Lincoln Federal No. 1 in Section 26, T21S, R32E, NMPM, in Lea County, New Mexico about 8 miles (13 km) east-northeast of the WIPP Site Boundary (Collins & Ware, Inc., 1991 pp. 1-4). On the third day of drilling and upon reaching a depth of 1292 feet, all of the circulating fluid was lost to the formation. The driller began hauling in water to continue drilling. Drilling with water continued for ten additional hours on the fourth day. A survey confirmed 100% circulation loss in the two foot interval from 1290' to 1292'.

> Attempts to seal the formation with cement over the next 5 days largely failed as evidenced by the continued loss of circulating water to the formation. Nonetheless, on the tenth day, drilling continued until an air pocket and brine flow were encountered at 2000 feet. Brine from this formation began filling the surface pit, which is used to contain the circulating fluid. Drilling continued for 1 1/2 hours with brine flowing into the pit. The driller then hauled eight loads of brine to disposal and continued drilling for 9 hours with partial returns of brine to the surface. Apparently, while the brine flowed to the surface, much of the brine continued to flow into the two foot interval between 1290' and 1292'. The drilling report documented an additional 7 hours of drilling with no returns. On the eleventh day, after 3 1/2 hours of drilling with no returns, air drilling was initiated. As drilling continued, the pit filled with formation brine. Once there was sufficient brine in the pit, the brine was used as the circulating fluid for drilling until the pit was nearly depleted. Then air drilling resumed until the pit again filled with brine (Silva, 1994, pp. 63-64).

U.S. EPA (1998, pp. 15-16) presents an argument that water inflow will prevent air drilling in the vicinity of the WIPP. The argument must be viewed with caution. Although EPA alludes to cost limitations, there is no cost analyses for drilling a specified well in the vicinity of WIPP. Instead, referring to information from one industry contact (unnamed) and applying methodology presented by Lyons (1984, p. 109), EPA determined that the reasonable upper bound for water removal under current air drilling practice is in the range of 10 to 20 gallons per minute (gpm). EPA maintains that water inflow into a hole drilled at the WIPP Site would originate primarily from Culebra Dolomite and calculates that wells in the vicinity of WIPP with transmissivities greater than 1×10^{-5} m^2/s identify areas in which water inflow would prohibit air drilling. Furthermore, EPA states “other wells in the area have transmissivities in the 10^{-6} to 10^{-5} m^2/s range, causing much of the WIPP Site to be borderline for feasible air drilling” (U.S. EPA, 1998, p.16).

The wells in the immediate vicinity of the WIPP shafts, H-1, H-16, and ERDA 9, each have transmissivities on the order of 10^{-6} m^2/s. That these would be “borderline for feasible drilling” is somewhat difficult to understand in view of the measured inflow data for that area, which ranged between 0.3 gpm to 0.9 gpm with an average of about 0.6 gpm (D'Appolinia, 1983, p. 5-2). And that was for the six foot diameter ventilation shaft. An oil and gas well would have a much smaller diameter, hence, an even lower inflow.

With respect to the EPA comment that "the reasonable upper bound for water removal under current air drilling practice is in the range of 10 to 20 gallons per minute," EEG contacted the drilling design engineers of ECD Northwest who confirmed that current air drilling technology could easily handle water inflows on the order of 500 gallons per minute. Moreover, water inflows during drilling can be successfully inhibited by a variety of methods including, for example, reacting a monomer and catalyst in the water producing zone to form a polymer skin. The feasibility of such treatments was a matter of cost. EEG did not ask for the estimated cost of actually air drilling a well at WIPP but simply wanted to know the upper bound for water removal under current air drilling practice.

The DOE concludes that air drilling is not well suited to WIPP based on discussion with fifteen drillers with experience in the area. The DOE report does not include any detailed engineering or economic analysis for the actual cost of underbalanced drilling of a well near WIPP. If DOE and EPA are going to rely on interviews with drillers, than they must also consider the published concerns of others in the industry including drilling fluid manufacturers and suppliers who compete in an industry that must stay at the cutting edge of technological developments. In their recent catalog of supplies, Clearwater, Inc., a company which manufactures and supplies chemicals for underbalanced drilling offers the following thoughts:

> It has been an industry wide misunderstanding that very few wells are suitable candidates for drilling balanced to underbalanced. Through recent technological advancements, many obstacles have been overcome and what was once unthinkable is today "NO PROBLEM". (Capitalized in the original).

In discussing recent technological developments in underbalanced drilling, Clearwater, Inc. also states:

> Many operators who have attempted air drilling and failed have abandoned the technique. These operators may not have kept abreast of the latest developments. The limited use of air drilling techniques, relative to fluid, is primarily a function of the limited knowledge of new developments and the industry's natural resistance to changing methods. The level of expertise in air drilling technology currently found is comparable to the industry's generally limited knowledge of hydraulic fracturing methods two decades ago.

The EPA should consult with the DOE Office of Fossil Energy. As one DOE sponsored study noted, unfamiliarity with light-weight fluids and the perception of high cost were the two primary reasons operators gave for not using light-weight fluids more often (Duda et al., 1996, p. 76). The DOE Office of Fossil Energy continues to participate in an effort to promote the understanding and use of underbalanced drilling technology.

2.5.1.5 Analysis Conclusions

Bredehoeft (1997a) identified how the drilling rate specified by the EPA Criteria cannot accommodate even a small technological change, such as using air drilling rather than brine drilling for resource recovery in the vicinity of the WIPP.

The DOE and EPA reject the air drilling scenario on the basis of regulatory considerations. Yet the DOE and EPA review of records to determine drilling practices did not include the Texas portion of the Delaware Basin despite verbal information referring to such drilling activities.

DOE and EPA's examination of the New Mexico records raises questions about the adequacy of such records to provide complete information on the use of underbalanced drilling in the New Mexico portion of the Delaware Basin.

The EPA arguments concerning the inability of air drilling to handle water inflow at the WIPP appear to lack merit given the actual measured inflows and the current state of air drilling technology.

The DOE interviews with drillers found that they would not consider using air drilling near the WIPP site. However, written statements by others in the air drilling industry, including the DOE Office of Fossil Energy, identify an industry wide misunderstanding that as led some operators to incorrectly conclude that some wells are not suitable to air drilling. They note that the limited use of air drilling techniques, relative to fluid, is primarily a function of the limited knowledge of new developments and the industry's natural resistance to changing methods.

2.5.2 The Improper Use of the Quasi-Static Method for the Prediction of Spallings

To quantify the consequence of drilling with air as the fluid used for bit lubrication and cuttings removal upon a drill intrusion at the WIPP, the EPA adapted the Quasi-Static spreadsheet model that was described in Hansen et al. (1997) for an air drilling scenario. The results of modeling the air drilling scenario can be found in U.S. EPA (1998). The model was originally designed for drilling with a brine mud medium. The code produced reasonable results for an air drilling model, in that it did not calculate extremely large stresses in the waste near the borehole, considering the large pressure difference between the intruding borehole and the highly pressurized repository. Therefore, it was assumed that the code could be used for the air drilling scenario. However, the model was not developed to predict failure. The code is only capable of calculating stresses in the waste assuming that no material has been removed. Extrapolating a failure from the results of the code misrepresents its design, and may lead to false interpretations.

2.5.2.1 Quasi-Static Model

The Quasi-Static model was developed with three main purposes (or elements): 1) to calculate the motion of the mud column up the borehole, 2) calculate the gas flow within and from the repository, and 3) to calculate stresses in the waste. All three processes are coupled by the pressure at the bottom of the borehole (bottomhole pressure), and are described quite well in Hansen et al. (1997) or Gross and Thompson (1997).

The implementation of the numerical model for the three elements was established by using two spreadsheets. The first spreadsheet calculated the gas flow and pressures within the repository as well as the motion of the drilling mud being expelled from the borehole from a high bottomhole pressure. The second spreadsheet calculated the effective stresses in the waste as a function of radial distance and time from the total stress exerted by the overburden rock and saturated waste and the pore pressure calculations of the first spreadsheet. This was accomplished by numerical integration of the governing equations in Gross and Thompson (1997) by the Runge Kutta method.

The name Quasi-Static refers to the steady state approximations to the analytical solution of the gas flow equation. The steady state analytical solution differs from a fully transient numerical model, and thus disregards some aspects of flow such as compressibility. The steady state solution assumes that the boundary condition at the borehole is constant. However, since the boundary will change in time during an intrusion at WIPP, the solution undergoes a series of steady state calculations to calculate the pore pressures in the waste and the mud motion up the borehole as a function of time. The solution has been verified by the transient flow calculations of the GASOUT code (Hansen et al., 1997). The results of the two codes show very close agreement.

Once the pore pressures in the waste are known, they can be used to calculate the effective stresses in the waste. If the pore pressures in the waste are greater than the total stresses within the repository and the strength of the waste, then the effective stresses are negative, indicating that the waste could fail. However, the code does not consider the removal of waste in the borehole cavity, and the calculation of pore pressures will decrease as the gas flows from the repository to the borehole. Once pore pressures decrease, the effective stresses increase positively, meaning that the carrying capacity of the waste from the overburden rock must increase. Once this happens, the waste will no longer fail. Since the code was not designed to handle waste removal, the estimation of failure can only be accurate at very early times (most accurate after the first time step). If the code did consider waste removal, the pore pressures would redistribute near the borehole cavity boundary, and the pore pressures in the waste would be higher. Higher pore pressures give rise to more waste failure. The calculation of waste removal was conducted in the code GASOUT (Hansen et al., 1997), and the option can be turned off for comparison with the Quasi-Static model.

2.5.2.2 Application to Air Drilling

The EPA used the Quasi-Static model to calculate spallings from an air drilling scenario (U.S. EPA, 1998) to dispel the scenario from a low consequence point-of-view. The use of the Quasi-Static model on an air drilling scenario to calculate waste failure and blowout is misleading in two ways. First, the calculation of drilling mud motion up the borehole was derived from forces that accelerate the mud upwards. The acceleration of the mud column depends on an incompressible fluid, i.e., the density is not pressure dependent. The input for the Quasi-Static model uses the density of the boring fluid to calculate the hydrostatic weight of the mud column. Since this is a constant, the weight is a function of the borehole length only. During an air drilling scenario, the air would decompress quickly near the top of the borehole, and the weight of the column would be less. The result would be higher gas flow from the repository, and hence lower total stress and pore pressures near the boundary. The EPA calculated that the blowout of the mud column would take 9.1 seconds. If the air were allowed to decompress, the acceleration of the air column would be greater than that calculated in the Quasi-Static model, and blowout would occur much more quickly than anticipated. The consequence could lead to higher releases of waste in the borehole cavity.

The second misleading interpretation of air drilling model with the Quasi-Static model is the amount of failed material extrapolated from the results of calculated effective stress. The effective stress is calculated from the difference between the total stress of the waste and overburden rock and pore pressures, and is quantified by the equation

$$\sigma ' = \sigma - \mu \qquad (2.5\text{-}1)$$

where $\sigma '$ is effective stress, σ is total stress, and μ is pore pressure (Terzaghi and Peck, 1948).

Effective stress is the stress applied to the grains of material in a saturated medium. Effective stress cannot be measured, and is only a calculated quantity from the other two constituents of the equation. In order for the material to fail in the borehole cavity, the pore pressure must be greater than the total stress of the repository. In normal applications, the total stress is always larger than the pore pressure, and the effective stress is the resultant stress applied to the material on the macroscopic grain level. For this case, where pore pressure is larger, the effective stress is less than zero, and hence cannot sustain the force of the material in contact. In addition to the total stress, the pore pressure must overcome the strength of the material before it will fail. Again, in normal geotechnical applications, the strength of soil in tension is practically zero for cohesionless material (sand and gravel), and nominal in clays. In this application, where cementation of MgO backfill is considered, along with the pressurization and saturation of waste material, the tensile strength was measured to be approximately 10±5 psi (0.07±0.04 MPa).

The results of air drilling from the EPA's analysis at WIPP is reproduced here in Figure 11. The figure shows effective stress versus radial distance within the repository at several times during the simulation. The EPA judged failure in this figure by estimating the point at which the effective stress is less than the strength of the material (indicating high pore pressure). This point is at 1 second from the beginning of the simulation, with a radial failure distance of 0.69 m (1.4 m^3 of uncompacted waste). After 1 second of simulation time, the pore pressure in the waste near the cavity begins to decrease, and the effective stress moves upwards (increases positively) towards the region of higher total stress.

It is stated here again that the code was not designed to calculate failure, and it can only be used to estimate the stresses in the waste assuming that no waste has been removed from failure. If failure of waste is to be assumed from the Quasi-Static model, then it can only be inferred from

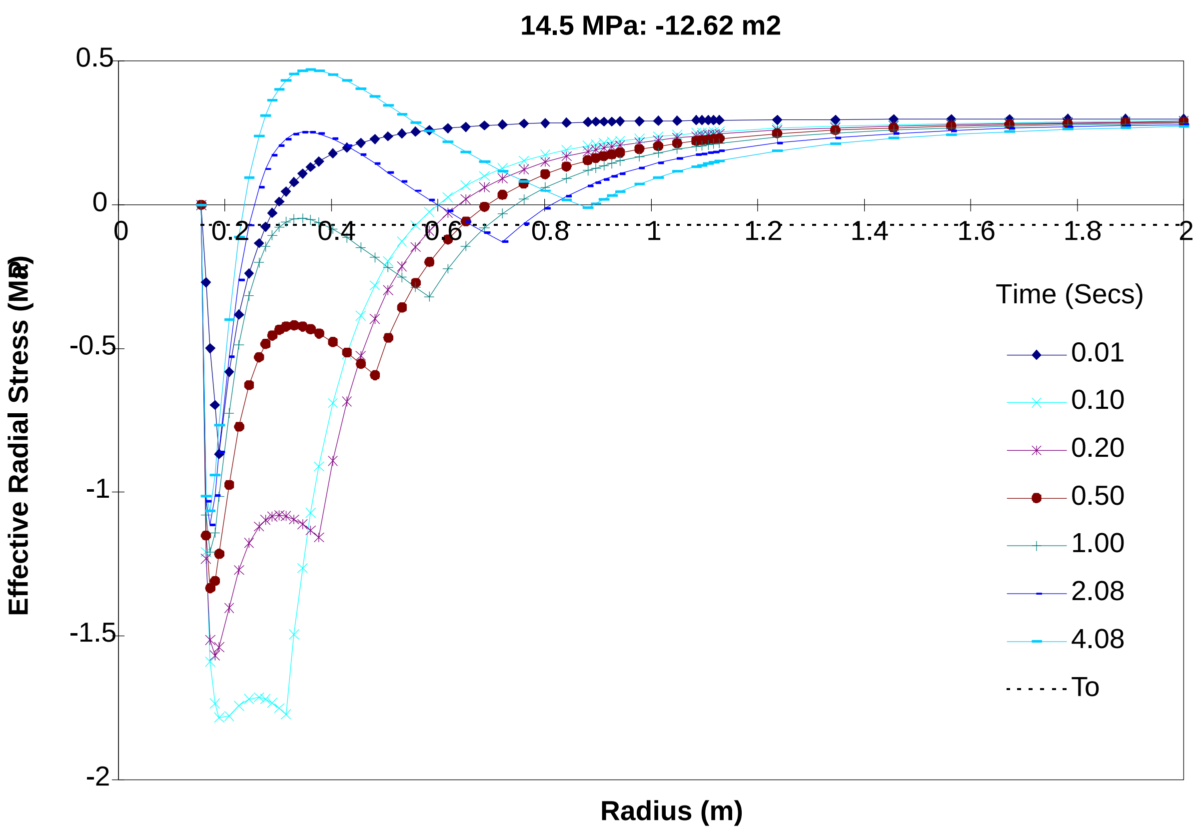

Figure 11. Effective Radial Stress As A Function Of Radial Distance For The EPA's Air Drilling Analysis.

early times during the simulation. To demonstrate the difference in the Quasi-Static model to a model that recalculates stresses after material removal (a.k.a. cavity growth) the results were compared using brine mud as the drilling fluid, since the cavity growth model cannot accurately predict failure with the use of air as a drilling medium. The results show that the Quasi-Static model predicts a failure radius (as estimated from effective stress) of 0.44 m, and the cavity growth model calculates a 0.25 m under the same condition. The same cavity growth model calculates a failure radius of 0.16 m when the option of failed material is turned off. So, the comparison tends to demonstrate that the removal of waste during the stress calculations will predict higher volumes of failed waste.

Intuitively, the results shown in Figure 11 would raise questions about the behavior of the system. Why does the effective stress sharply decrease from 0.01 seconds to 0.1 seconds then gradually rise throughout the remainder of the simulation? Does the system stop predicting failure after 1 second? What is the effect of tangential stresses in the waste? How does the system respond to varying repository parameters? All of these questions are relevant to the understanding of the Quasi-Static model and to the prediction of stresses in the waste from an air drilling event.

The effective stress is simply the difference in the calculated total stress and calculated pore pressure. Figure 12 shows the relationship between these quantities for three separate times for the EPA's analysis of air drilling. The left plot shows the first time step, at 0.01 seconds from time of intrusion. One can see immediately that waste failure occurs due to a slightly higher pore pressure, with the radius of failure being 0.27 m. The relatively large failure at this time is due to the unsmooth function of the pore pressure in the waste, which carries over to the effective stress. The same can be seen the two other plots of 0.1 and 1 second from intrusion time. The effects of the unsmooth pore pressure profile average out as the time from intrusion increases, but is one the reasons for increase in effective stress at later times.

The high radial failure as seen in the effective stress from the unsmooth nature of the pore pressure can be dispelled, once a more accurate code is used to model air drilling. Figure 13 shows the effective stresses as calculated in GASOUT from an air drilling scenario. The code was

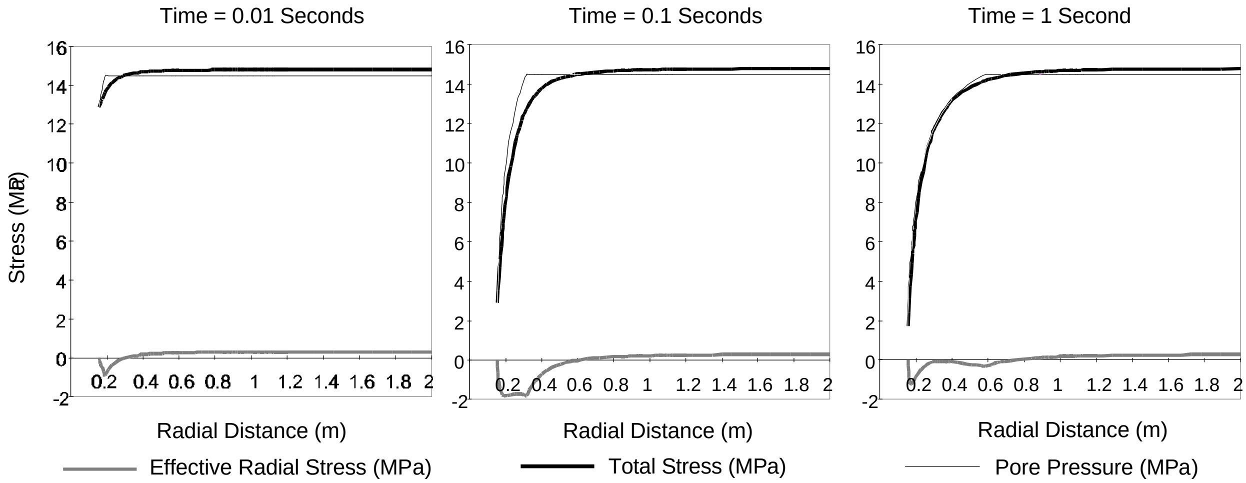

Figure 12. Effective Stress, Total Stress, and Pore Pressure Profiles in the waste at three independent times from the EPA's Analysis of Air Drilling.

run with the cavity growth option turned off and the same input assumptions as used in the Quasi-Static model. Although the code cannot predict failure accurately with the option of failed material removal to be removed (due to multiple layers of cascading waste during a single time step), the code can calculate the pore pressure distribution and effective radial stresses that match quite closely to the Quasi-Static model with the option turned off. Figure 13 shows that at 0.01 seconds from intrusion time, the radial failure is 0.38 m, which is higher than the Quasi-Static model. Although, it must also be noted that the pore pressure eventually decreases after this initial time, at 0.1 and 1 second from the time of intrusion. The conclusion gathered from this analysis is that the pore pressures are smooth through the waste, and subsequently predicts a much higher negative effective stress at earlier times.

Smoothness aside, the major discrepancy between the model and the physicality of the scenario is the fact that material is not being removed during the time that material could fail. This would have a major impact on the results, especially pore pressure, and hence effective stress. If material were allowed to be removed, the pore pressures would stay higher, because the low pore pressure waste would have been removed. The pore pressures would then be recalculated with the remaining waste at higher pressures. This is evident in Figure 13-11 of Hansen et al. (1997). The figure shows the calculations of with and without material removal assuming brine mud is the drilling fluid. The curve showing that material is removed has higher pore pressures in the waste.

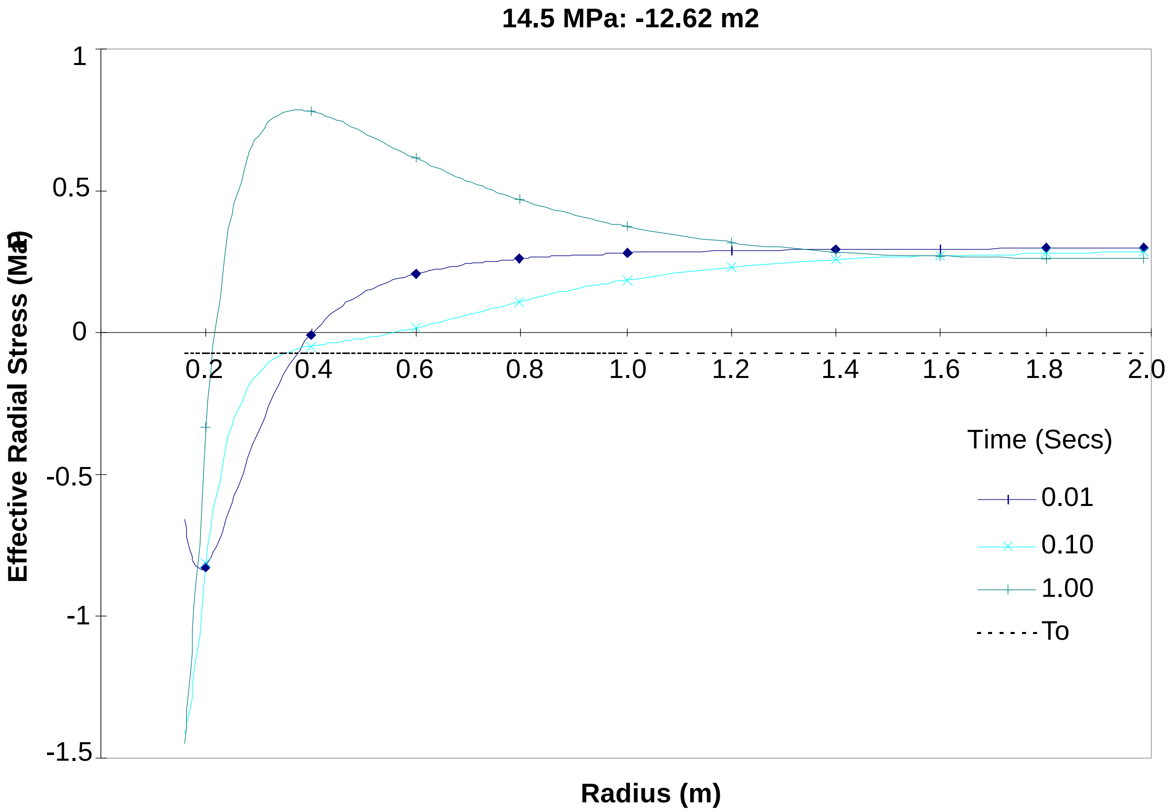

Figure 13. Effective Radial Stress As A Function Of Radial Distance Using GasOut For The Air Drilling Analysis.

Though the difference in pressures between the two curves is slight, it would have a significant impact on the effective stresses and potential releases. For Figures 1 and 3 above, the pore pressures artificially decrease from the flow of gas in material that should have been removed. Therefore, the judgment of waste failure from Figure 11 leads to false confidence by underpredicting waste failure.

Along with the calculated radial stresses, tangential stresses will also exist in the waste. As radial stresses are directed inwards to the borehole center, the tangential stresses are directed along the tangential paths of the hemispherical cavity, and are perpendicular to radial stresses. Essentially, the tangential stresses are compressive stresses acting along the circumference in a spherical geometry, and radial stresses are tensile stresses acting along the radius (or compressive, depending on the nature of the pore pressure and total stresses).

The effective tangential stresses in the waste were calculated much like that of the radial stresses, with effective stress equating to the difference in total stress of the overburden rock and pore pressure. Since the tangential stresses are always in compression, the resultant effective stresses are above zero, and hence no failure occurs from compressive tangential stresses.

The radial and tangential stresses are related by a yield potential, as stated in Jaeger and Cook (1976), which incorporates the compressive strength, internal angle of friction, and cohesion of the waste, by the formula,

$$\sigma_\theta - C_o - \sigma_r \tan^2 \alpha > 0 \qquad (2.5\text{-}2)$$

where σ_θ is the tangential stress (major principal stress), σ_r is the radial stress (minor principal stress), C_o is the compressive strength, and α is equivalent to

$$\alpha = (\pi/4) + \tfrac{1}{2} \phi \qquad (2.5\text{-}3)$$

where ϕ is the angle of friction. The left hand side Equation 2 must be greater than zero for yielding to occur.

Figure 14 shows the results of Equation 2.5-2 plotted against radial distance. The first observation is that there is potential for yield out to 2 seconds from the time of intrusion. The yield crosses the axis at approximately 0.8 m, resulting in an uncompacted volume of 2.1 m^3. This is an increase of 33% from the initial estimate stated in the EPA's analysis. The curves also seem to be highly influenced by the discontinuity in pore pressure calculations, and can be seen in Figure 14 by the second peak in the curve as radial distance increases. When compared to the yield potential calculated from GasOut, which calculates a smooth function of pore pressure, the limit for yield is 0.7 m at 0.1 seconds from intrusion (as compared to 0.6 m from the Quasi-Static model). After this time the yield is essentially zero.

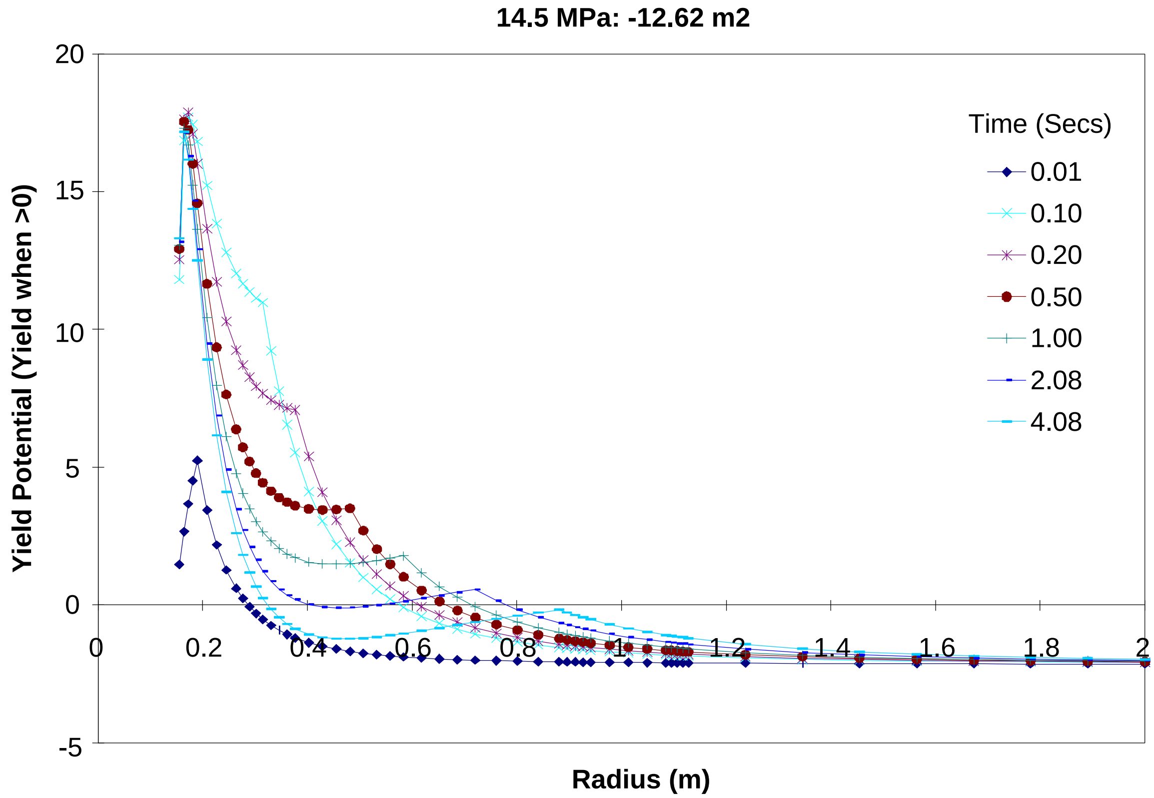

Figure 14. Yield Potential for EPA Air Drilling Analysis. The Figure Represents Equation 2 (above) vs. Radial Distance. Yield Will Occur When the Potential is Greater than Zero.

After the analysis of air drilling using the Quasi-Static model was complete, the EPA dismisses the consequence of air drilling based on the amount of expected failure in the borehole cavity. The volumes, as seen above, do not exceed the 0.5 to 4.0 m^3 of waste, which were calculated in the CCA as being the maximum possible spalled volumes. Therefore, since expected failed volumes are less, they will not affect the CCDF (Complimentary Cumulative Distribution Function) calculations of the CCA, or PAVT. One must keep in mind, however, that the analysis was for only one set of repository assumptions, and that the calculated failures can change drastically when the assumptions are changed.

To demonstrate the response of the model to different input assumptions, Figure 15 shows a simulation in which the repository is increased from the nominal 14.5 MPa that was used in the EPA analysis to 14.8 MPa. The higher pressure is the maximum pressure that the repository will

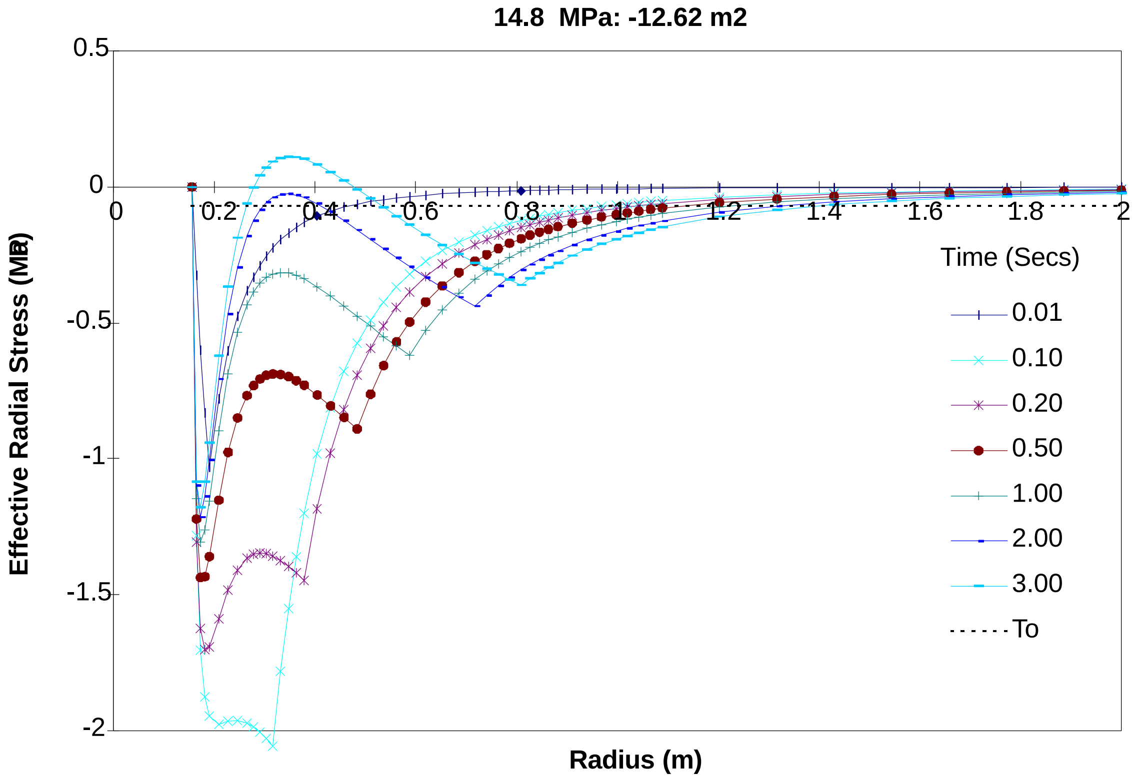

Figure 15. Effective Radial Stress As A Function Of Radial Distance For An Increased Pressure For The Air Drilling Scenario.

sustain for long periods of time, and is the lithostatic pressure of the overburden rock. If gas pressures are above lithostatic, the weak stratigraphic layers will fracture until sufficient energy is released and the pressure returns to the minimum fracturing pressure. The results of Figure 15 are astounding. The figure shows that a nominal increase in pressure will significantly increase potential releases. At 1 second after initial intrusion, the radial distance of failure is 1.22 m (7.58 m^3 of uncompacted waste). Although not shown, the waste will continue to fail during the entire 9 second simulation, in which the radial distance increases to approximately 1.65 m (19.1 m^3 of uncompacted waste). These volumes are greater than the 4.0 m^3 maximum calculated in the CCA, and perhaps would have an impact on the CCDF calculations if air drilling scenarios were considered in the CCA.

The input assumptions for the EPA air drilling analysis also assumed a waste permeability of 2.4×10^{-13} m^2, which is slightly higher than what was used in the CCA, but consistent with the PAVT. It is reasonable to assume that the waste permeability could vary within the repository, and exhibit much lower values. The investigation by Dr. Frank Hansen and coworkers (Hansen et al., 1997) used a numerical code for gas flow within the repository during an intrusion, which could spatially vary the waste permeability. The results from the analysis showed that the pore pressure gradient will be very high near the borehole cavity. The higher pressure gradients will cause the total stress to decrease and the effective stress to increase negatively, which may lead to higher waste failures.

When the waste permeability was decreased in the Quasi-Static model for air drilling, the code predicted the opposite behavior. Table 3 shows the results of radial failure at various times for different waste permeabilities. The initial repository pressure was 14.5 MPa for these calculations. In the most extreme case, when repository pressure is 14.8 MPa and waste permeability is increased to $10x10^{-13}$ m^2, the failure at 5.8 seconds (blowout) is approximately 1.9 m (28 m^3 uncompacted volume).

2.5.2.3 Modeling Conclusion

The Quasi-Static model, as introduced in Hansen et al. (1997) was used to model the expected releases during an air drilling scenario into the repository at the WIPP (U.S. EPA, 1998). The investigation was initiated by the EPA to satisfy the contention that if air drilling were to occur, then the consequences would not lead to significant changes in the CCA (or PAVT). The Quasi-Static model uses a Runge-Kutta method for solving the analytical equations for 1-D flow of gas through porous media and the blowout of the drilling fluid. In addition, it solves the analytic expression for radial and tangential stresses in the waste near the wellbore. The model is a simplistic analysis, in that it solves a series of steady state approximations to flow. The model is established on two spread sheets.

Pressure = 14.5 MPa	@ 1 second	@ 1.5 seconds	@ 2 seconds
$2.4x10^{-13}m^2$	1.38 m^3		
$1.7x10^{-13}$ m^2	1.26 m^3	1.43 m^3	
$1.0x10^{-13}$ m^2	1.11 m^3	1.24 m^3	1.35 m^3

Table 3. Estimated Failure Volumes for the Quasi-Static Model Under Varying Waste Permeability

The EPA's analysis showed that under expected repository conditions, the release from an air drilling scenario would not be greater than 1.4 m^3, and hence much less than the predicted releases of the CCA and PAVT. Therefore, their conclusion of the air drilling analysis stated that based on its [the Quasi-Static model] conservatism, air drilling need not be considered in the CCA.

Several conceptual flaws can be seen from the analysis in U.S. EPA (1998). First, the code was not designed for failure. It was only designed to calculate the stresses in the waste, assuming no waste failure and subsequent removal occurs. Waste removal will have significant impact on the actual pore pressures that may exist. Second, the code was not designed to handle a compressible fluid as the drilling medium. The code assumes that water (or some other incompressible fluid) will be ejected from the borehole upon blowout. In reality, the gas from air drilling will expand, causing the weight of the drilling fluid to be over predicted in the model. The over prediction will cause the flow of the gas from the repository to be less, and time for complete blowout to be longer.

The code also only approximates the pore pressures in the repository by assuming steady flow. As seen in Figure 12 (above), the steady flow assumption causes the pore pressure profile to be unsmooth. This characteristic, when combined with total stress of the overburden rock, produces oddly varying effective stresses in the waste. This shows that the code produces unreliable results for an air drilling scenario. When effective stresses are compared to the results of a code that calculates the time-dependent flow and pore pressures (Figure 13, above), the effective stresses are much lower (higher in the negative direction) than the Quasi-Static model at early times. Beyond the first couple of time steps, the code starts to be less accurate, and pore pressures begin to decrease in waste that should have been removed.

The analysis of air drilling by the EPA also only showed one particular view of repository conditions. The uncertainty in repository parameters were not mentioned in the report. The uncertainty in the parameters is presented in this report, and the analysis shown above demonstrates the nonconservative approach of the air drilling scenario. For example, the repository pressures can be above the assumed 14.5 MPa, and may be as high as 14.8 MPa, which is the lithostatic pressure exerted by the overburden rock at the depth of the repository. When the Quasi-Static model was increased to 14.8 MPa, the code predicted stresses that would lead one to intrepret a failure of 19.1 m^3. This is over ten times the predicted value stated in the EPA analysis. Also, by changing the waste permeability to include the uncertainty of future and existing waste, the code predicted much different results.

In conclusion, the results of the EPA analysis do not reasonably estimate potential spallings releases. The use of a code for air drilling that was developed for an incompressible fluid appears inappropriate. The code cannot accurately predict failure beyond the initial time intrusion due to the assumption that waste will not be removed. The code should only be used to estimate the stresses in the waste when no failure has occurred. The fact that waste is not removed underpredicts the extent of failure, and provides false confidence in that blowout will be less than what may actually occur in field conditions. The results, as stated in the EPA's analysis, is not conservative, and should be re-examined based on a conceptual model that is designed to handle transient flow conditions and compressibility of the repository gas as well as the compressibility of the boring fluid.

2.6 FLUID INJECTION

The petroleum reservoirs surrounding and underlying the WIPP are potential candidates for fluid injection to recover a substantial amount of crude oil reserves (Broadhead et al., 1995; Silva, 1996). For oil field operations in southeastern New Mexico, the problem of water migrating from the intended injection zone, through the Salado Formation, and onto adjacent property has long been recognized (Ramey, 1976; Bailey, 1990; LaVenue, 1991; Silva, 1994; Van Kirk, 1994; Ramey, 1995; Silva, 1996). The observation continues to be of concern for proposed oil field waste disposal into the Salado Formation (Kehoe, 1996; Cone, 1996). Concerns about unexplained water losses due to solution mining (U.S. DOE, 1980, 2-7; U.S. DOE, 1993, 26), potential oil field development (U.S. DOE, 1980, 2-10), or future oil field waterflooding (Griswold, 1977, 13) helped eliminate other sites from consideration for the disposal of transuranic waste (U.S. DOE, 1980; Silva, 1996). Moreover, "... at the time the WIPP site was selected, one of the stated advantages over other locations was that the lack of petroleum development near WIPP was not conducive to secondary recovery techniques" (Weart, 1993).

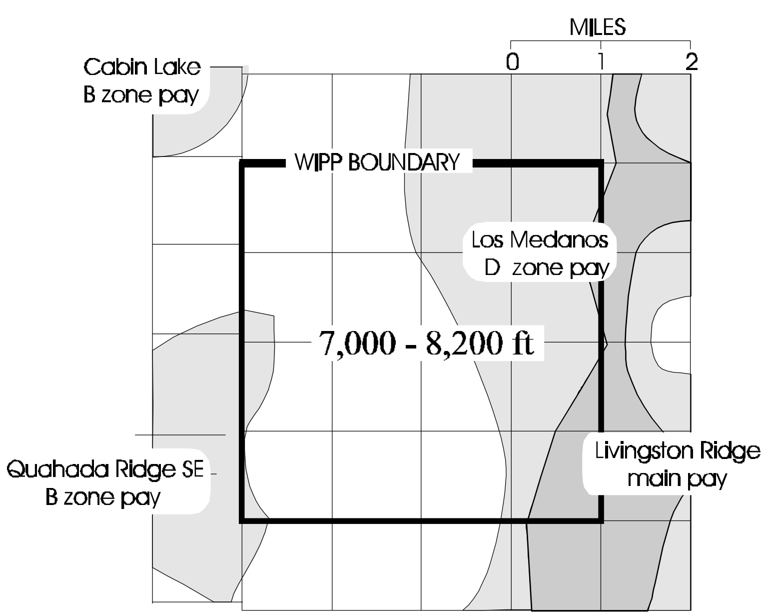

Fig. 16. Areas of Known and Probable Oil And Gas Resources for Delaware Pools. Broadhead et al., 1996.

By now it is well established that the WIPP vicinity is rich in oil and gas resources. The reservoirs are conducive to secondary resource production by waterflooding (Broadhead et al., 1995; Broadhead et al., 1996; Silva, 1996), the use of carbon dioxide flooding adjacent to the WIPP has been postulated (Boneau, 1992, 2) and the use of carbon dioxide flooding throughout the Delaware Basin is being explored with support by the DOE Office of Fossil Energy (Dutton et al., 1996; Dutton el al., 1997; Murphy, 1997) . Nonetheless, the EPA proposes to accept the DOE CCA position that fluid injection can be ruled out as a potential scenario and, hence, need not be considered in the performance assessment calculations. It is essential that the viability of these issues be assessed to ensure confidence in conclusions regarding risks from human intrusions.

2.6.1 Regulatory Argument to Eliminate Actual Resource Recovery Activities

For the recovery of oil and gas resources within the designated four-mile by four-mile boundary, the EPA proposes to accept the DOE argument that the actual recovery method need not be considered in the performance assessment. The DOE need only consider the actual drilling event (U.S. EPA, 1996). The presence of the oil and gas resources are known, the use of fluid injection is a well established oil recovery practice in the Delaware Basin, water injection for salt water disposal and enhanced oil recovery is already underway near the WIPP, and the history of water migrating from leaking injection wells through the Salado Formation in southeast New Mexico is well documented (Silva, 1996). However, the DOE does not need to consider the impact of such recovery methods in the performance assessment calculations. Such scenarios can be rejected for consideration on the basis of regulation (U.S. EPA, 1996).

The concept of rejecting a scenario on the basis of regulation allows the DOE the latitude to eliminate any inadvertent human activity that could result in a consequence greater than that of exploratory drilling (Sandia, 1992, 4-4; Silva, 1996, 158). The other grounds for rejecting scenarios are probability and consequence. These two criteria are potentially quantifiable and are an inherent part of the EPA Standards for the disposal of transuranic waste. However, probability and consequence are not considered if a scenario has already been eliminated on the basis of regulation. The International Review Group expressed reservation about rejecting a scenario solely on the basis of regulatory considerations. In their review of the WIPP project, they state:

> 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, p. 19).

2.6.2 Low Consequence Argument Relies on Untested Model

For the low consequence argument, the EPA has accepted the modelling results of Stoelzel and O'Brien (1996) and Stoelzel and Swift (1997) and has rejected the modelling results of Bredehoeft (1997b). The DOE maintains that a leaking injection well in the vicinity of WIPP is a low consequence event because the model of Stoelzel and O'Brien does not predict a substantial inflow of brine into WIPP in such an event. But a very fundamental question remains. Can the codes model a documented high consequence event? In other words, can the DOE codes take the injection data and geologic data from the highly visible Hartman case and reproduce what is believed to have happened at the Bates Lease (Hartman, 1993, Van Kirk, 1994, Powers, 1996). At a minimum, the codes must be able to move a substantial amount of water through a single zone of the Salado Formation, two miles in the updip direction, and in a short period of time, about 12 years. If the model, as used by Stoelzel and O'Brien, can not move the water to the Bates Lease, then any low consequence argument based on this model may be meaningless. At this point there is no indication that a verification with actual field events has been conducted and a low consequence argument based on an unverified model could be characterized as speculation.

2.6.3 Low Probability Argument Conceived by EPA contradicted by DOE Observations and Actual Oil Field Experience

The EPA also raised questions regarding DOE's consequence analysis and "concluded that regardless of the consequence argument, the probability of such an injection event that affects WIPP is very low, and so this FEP can be eliminated on the basis of low probability" (U.S. EPA, 1997b, Card 32-42).

But, the DOE chose to examine consequence rather than probability, as noted by Stoelzel and O'Brien, "[b]ecause certain petroleum practices are hard to define in a probabilistic sense (for example, the quality of the cement and/or casing and its ability to withstand leaks over time)..."(Stoelzel and O'Brien, 1996, 8). Nonetheless, EPA assigned probabilities to certain petroleum practices, such as an undetected leak occurring in the annulus, and multiplied the probability of each event and calculated that the *realistic* probability of a injection well impacting the repository was only one in 667 million (U.S. EPA, 1997h, Table Q).

The EPA is relying on an optimistic view of future injection well performance which does not reflect the actual experience of documented waterflows in the Salado Formation in water flood areas throughout southeast New Mexico. As noted in EEG-62, waterflows are not randomly distributed, but are strongly correlated with waterflood operations (Gallegos and Condon, 1994, p. 2). Rules and regulations governing the use of oil field injection wells have been in place for decades and the records of waterflows indicates the level of their effectiveness. For example, the enabling orders for the Rhodes Yates waterflood (Campbell et al., 1964; Cargo et al., 1969; Ramey, 1977) required operating in accordance with Rules 701, 702, and 703 (Hartman, 1993, 4). Rule 702 requires cementing and casing of injection wells to prevent the movement of fluids out of zone. Rule 703 requires operation and maintenance practices to assure no significant fluid movement through vertical channels adjacent to the well bore. Further, the entire operation, including producing wells, must be operated and maintained to confine the injected fluids to approved intervals. The documented problems with the Rhodes Yates waterflood (Hartman, 1993; Hererra, 1995) and with waterfloods and salt water injection throughout the southeast New Mexico (Ramey, 1976; U.S. GAO, 1989; Bailey, 1990; Krietler et al., 1994) clearly indicate the limitations of taking credit for state or federal regulations, new or old, for protecting WIPP. Furthermore, there are literally hundreds of documented waterflows for District 1 and District 2 of southeastern New Mexico. Those records are maintained by the NMOCD. Summaries are included as Appendix 8.9.

To determine its probability, EPA assigns individual probabilities to events such as a leak going undetected and one of those wells leaking into the annulus. However, EPA provides no references to any field studies to demonstrate that these probabilities have any basis in the actual experience of the oil and gas industry. For example, did EPA actually obtain and review the repair records for oil and gas wells in the Delaware Basin? EPA comments that the Underground Injection Control regulations have proven effective since 1984. Did EPA review well files to determine that all required testing for each injection well had been completed on schedule? For example, DOE sponsored a study in which it was suggested that the Todd 26 Federal #3 was the well most likely responsible for anomalous water level rises observed for the H-9 Culebra observation well (Bailey, 1990; LaVenue, 1991). Did EPA verify that the New Mexico Oil Conservation Division had a record of the mandatory annual Bradenhead test for each year since 1984 and the mandatory mechanical integrity test every fifth year since 1984? The well passed a mechanical integrity test on August 16, 1995 (Silva, 1996, 127). Are there records filed with the NMOCD, which administers the UIC, to show that the well was tested in 1990 and 1985? If not, just how effective are the rules and regulations with respect to underground fluid injection and how did EPA take that observation into consideration in its determination of the probability of a leaking well impacting the performance of the repository? EPA should address all of these issue in the final rule.

There is another issue of concern. 1) If EPA accepts DOE's argument that it is not necessary to examine other criteria once a scenario is rejected on the basis of one criteria (relevance, regulation, probability, or consequence) and 2) if EPA accepts DOE's argument that fluid injection can be rejected on the basis of low consequence, why did EPA feel it was necessary to submit a low probability argument for the fluid injection scenario? By publication of a fluid injection probability calculation, it appears that EPA was not comfortable with rejecting an important scenario such as fluid injection on the basis of one criteria. EPA felt it was necessary to examine another criteria. EPA does not provide any guidance as to which other scenarios would require examination against one, two, three, or all four criteria.

In summary, EPA's rejection of the fluid injection scenario on the basis of low probability is contradicted by the observation that "certain petroleum practices are hard to define in a probabilistic sense" (Stoelzel and O'Brien, 1996, 8). EPA's probability calculation does not coincide with the observation that there is a history of out of zone water in waterflooded areas despite rules and regulations that have been in existence for decades. (Gallegos and Condon, 1994, p. 2; Silva, 1996, 155). It is not clear that EPA has a defensible basis for assigning probabilities of individual events in calculating a *realistic* probability of a injection well impacting the repository as only one in 667 million (U.S. EPA, 1997h, Table Q). Given EPA's efforts to provide a second basis for rejecting the fluid injection scenario, it is logical to conclude that EPA recognizes that scenario rejection may require meeting two or more criteria. The observation raises questions about each and every other scenario rejection.

2.6.4 EPA Position on CO_2 Injection in Conflict with Literature and Public Record

The potential leakage of injected carbon dioxide into the repository is of concern. Carbon dioxide must be injected into the deep target zone at sufficient pressure to generate a miscible displacement. In the event of leakage into an overlying zone, such injection could propagate a fracture and/or serve as a driving force for moving fluids through various flow paths. In the event carbon dioxide enters the repository, one might anticipate the formation of plutonium carbonates and nesquehonite and a reduction of the repository pH, each of which results in higher plutonium solubilities.

The EPA believes that the potential impact of CO_2 injection on the WIPP Site is very low because the EPA does not anticipate that CO_2 injection for oil recovery will be widespread practice in the future near WIPP (U.S. EPA, 1997b, Card 23-131). The EPA technical support document makes reference to a technical article (Thrash, 1979) suggesting that there may be a remote possibility that CO_2 enhanced oil recovery may also be suitable for some of these types of reservoirs (U.S. EPA, 1997h, 1997i) The EPA also notes DOE's opinion that CO_2 flooding in the vicinity of WIPP is highly unlikely (U.S. EPA, 1997b, Card 23-132).

DOE's position is at odds with the following observations. First, CO_2 flooding has been demonstrated to be quite successful in mature fields in the Delaware Basin such as the TwoFreds (Silva, 1996, pp. 142-145). Second, the DOE continues to sponsor university research on Delaware Basin oilfields, such as the Geraldine Ford and the West Ford, aimed at optimizing infill drilling and

CO_2 flooding throughout the Delaware Basin (Dutton et al., 1996, 1997). Third, oil and gas companies continue to purchase mature fields, such as the El Mar in the Delaware Basin, specifically for carbon dioxide flooding (Moritis, 1993; Silva, 1996). Fourth, the recently drilled reservoirs surrounding the WIPP such as Cabin Lake, Livingston Ridge, Los Medanos, and Lost Tank have oil and reservoir characteristics (Brown, 1995; May, 1995a; White, 1995; May, 1995b) that easily qualify them as potential candidates for future CO_2 flooding using the enhanced oil recovery (EOR) screening criteria described by Taber, Martin, and Seright (1997a, 1997b).

In its supporting documentation (U. S. DOE, 1997d) the DOE cites only one reference from the CO_2 flooding literature, a 1980 preprint of an SPE presentation. The body of literature on oil field carbon dioxide flooding is certainly more extensive and much has been published since 1980, including analyses of the issues raised in that 1980 preprint (Silva and Orr, 1987). Furthermore, the DOE document fails to reference the published proceedings (Silva, 1996) of a workshop on fluid injection which discusses in much more detail evidence of CO_2 flooding activities in the Delaware Basin. The EPA technical support document on fluid injection (U. S. EPA, 1997h) also fails to reference the published proceedings of the EEG workshop, which included participation by EPA staff.

With respect to the EPA documentation, the EPA offers three reasons why it believes that CO_2 will not be a widespread practice in the future near WIPP, but the EPA offers no supporting references for these reasons. (U. S. EPA, 1997b, Card 23-131).

1) EPA maintains that CO_2 injection costs far more than brine injection due to the easily available sources of brine and the injection quantities required.

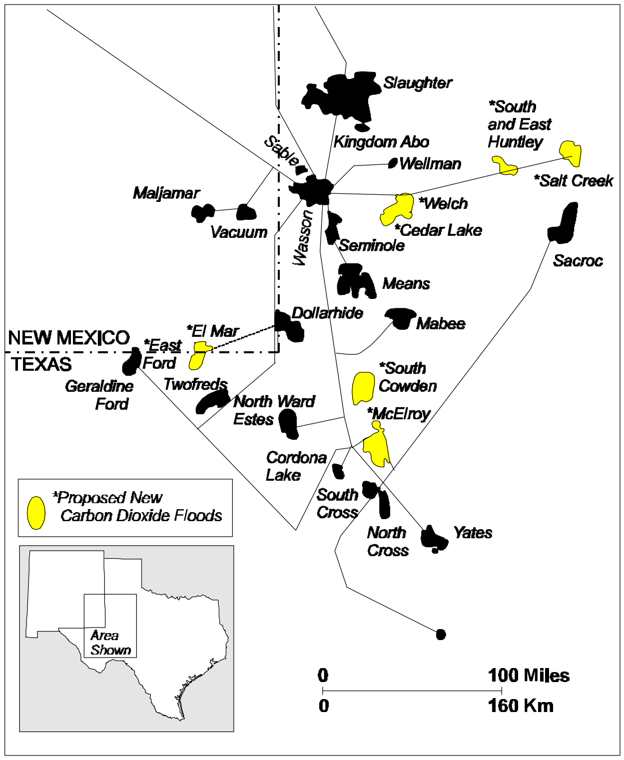

Fig. 17. Permian Basin CO_2 Pipelines and CO_2 Floods (Moritis 1993; Silva 1996)

This statement fails to recognize the availability of carbon dioxide in southeast New Mexico, the practice of conserving water whenever possible, the history of CO_2 flooding in the Permian Basin including parts of the Delaware Basin, the efficiency of a miscible type displacement to increase oil production and extend oil field life, and the willingness of local governments to work with companies to encourage the use of CO_2 flooding. If the EPA statement had any merit there would be no CO_2 flooding used in the Permian Basin or any other oil field for that matter. But as shown here, there is extensive CO_2 flooding in the Permian Basin as a result of a large investment in pipelines across New Mexico to bring carbon dioxide from southeast and southwest Colorado and northeast New Mexico to West Texas. Moreover, the DOE recognizes the potential for enhanced oil recovery in the Delaware Basin and continues to fund research on reservoir characterization and field trials to explore the most feasible use of carbon dioxide throughout the basin (Dutton et al., 1997; Murphy, 1997). In addition to encouragement by federal and state government, county governments in New

Mexico also have the authority to encourage the development of CO_2 flooding operations through tax reduction incentives. For example, under authorities granted by the state, Lea County recently granted Texaco $500,000 in property tax relief to construct a facility to provide CO_2 for injection into the Vacuum Field. In addition to extending the life of the oil field by 20 years, adding 100 construction jobs over the next three years, and providing 15 million dollars in tax revenues, the benefits to Lea County also include:

> Conserving an estimated 130 million barrels of fresh water that, thanks to CO_2, won't be pumped into the field over the next two decades, plus an additional 130 million barrels of saltwater that will be raised from the field (via CO_2 injection) and can then be used for water flooding elsewhere (Jacobs, 1998).

Waterflooding is used to restore energy to a depleted reservoir but displacement efficiency is limited to an immiscible type displacement. The long recognized favorable characteristics of carbon dioxide flooding include the preferential dissolution of CO_2 into the oil rich phase, the reduction of oil viscosity, the swelling of the residual oil droplets, the preferential extraction of lighter hydrocarbons, and the development of a miscible type displacement.

2) The EPA maintains CO_2 injection is more difficult to control, since the rocks are more permeable to gas than to brine, higher injection pressures are required to maintain desired pressure configurations.

It is not clear why EPA believes that the relative permeability of gas and brine in rock has a role in making CO2 injection more difficult to control. Please provide a more detailed explanation and references for the statement.

3) The EPA maintains the presence of gas could inhibit production in that any gas present will be in the nonwetting phase and will occupy the portions of the oil reservoir that have relatively large apertures.

The EPA did not provide any references for this statement. EPA should refer to the results of Monroe et al., (1990) for the effect of dissolved methane on a one dimensional CO_2 flood. Their analysis "indicates that high displacement efficiency is possible even when two-phase flow occurs throughout the displacement and that high recovery is possible even when a live oil is displaced below its bubblepoint pressure (BP), if the pressure is above the minimum miscibility pressure (MMP) for the same oil with all methane removed" (Monroe et al., 1990, p. 423). EPA's third argument for dismissing CO_2 flooding does not appear to be reasonable.

2.6.5 EPA Technical Support Document Inadequate on CO_2 Fluid Injection

The EPA technical support document states "technical articles indicate the remote possibility of CO_2 enhanced oil recovery may also be suitable for some of these types of reservoirs (Thrash, 1979)." EPA references one early article for a reservoir in the Delaware Basin, the Twofreds field. EPA does not reference EEG-62 (Silva, 1996) which discussed the successful Twofreds carbon dioxide flood based on more current literature (Wash, 1982; Kirkpatrick et al., 1985; Flanders and DePauw, 1993).

The EPA Technical Support Document also states "at this time, the only examples of CO_2 injection enhanced recovery techniques are some distance from the WIPP site and under much different geologic conditions (Magruder 1990; Thrash, 1979)." The statement is incorrect. As shown in Figure 17 and in EEG-62, there are many CO_2 enhanced oil recovery injection projects. It is also inaccurate to argue that the field in the Thrash article is under much different geologic conditions. The Twofreds field is in the Delaware Basin and produces from the Bell Canyon Formation, which is found in the upper part of the Delaware Mountain Group. The Cherry Canyon and Brushy Canyon Formations lie further down in the Delaware Mountain Group and are the known oil bearing formations in the vicinity of WIPP. Most importantly, each of these oil bearing formations resulted from saline density currents as the depositional processes (Harms and Williamson, 1988). Hence, the EPA technical support document (U. S. EPA, 1997h, vol. 1, p. 26) is incorrect in stating that the CO_2 flood at Twofreds is under ***much*** different geologic conditions.

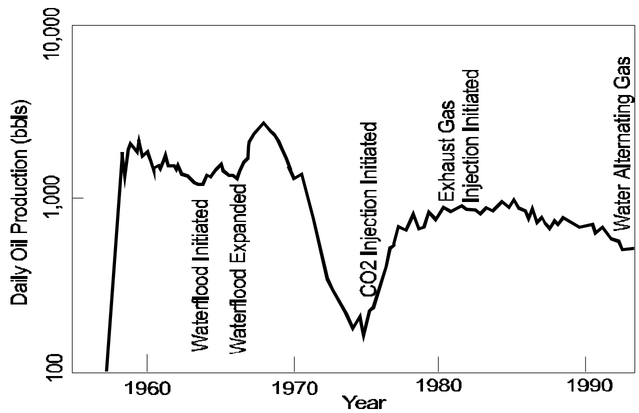

Fig. 18. Production History of Twofreds (After Flanders and DePauw 1993).

EEG-62 (Silva, 1996) discussed the performance of the Twofreds Field. The field is located in the Delaware Basin and produces from the Bell Canyon Formation of the Delaware Mountain Group. The reservoir is about 3/4 mile wide and is about five miles long with a net thickness averaging about 16 feet. The field was discovered in 1957. The Twofreds Field, like other Delaware fields, has always produced large volumes of water. After six years of primary production, a pilot water injection project was initiated in May 1963. A full scale waterflood was brought on line in January 1966. The project showed that oil from a Delaware reservoir with a high water cut could be recovered profitably (Jones, 1968). From 1963 to 1973, waterflooding, an immiscible displacement process, had produced 2 million barrels of oil. But by 1973, the amount of oil produced by waterflooding had dropped down to 160 bbls oil per day. As shown, carbon dioxide flooding, a miscible displacement process, increased oil recovery from 160 bbls oil per day to 1,000 bbls oil per day. By 1982, carbon dioxide flooding had produced an additional 2 million barrels of oil (Wash, 1982). The purpose of the Twofreds carbon dioxide flood to was demonstrate economic feasibility. The field continued to produce based on its economic merit (Kirkpatrick et al., 1985) and demonstrated that carbon dioxide can economically recover tertiary oil from a depleted, waterflooded Delaware sand reservoir (Flanders and DePauw, 1993). As of 1993, oil production from the Twofreds was averaging 500 bbls per day (Flanders and DePauw, 1993; Silva, 1996).

As a practical matter, EPA may not have enough information to conclude whether the oil fields adjacent to WIPP are conducive to carbon dioxide flooding. As noted by Silva (1996, 162), due to federal and state restrictions on drilling for petroleum in potash deposits, 85% of the area immediately surrounding the WIPP has yet to be drilled and directly tested for its oil and gas reserves. A production history is also needed to gain some understanding about the local geology of the oil producing zones. However, some drilling for oil and gas production adjacent to WIPP has been allowed. Coupling the enhanced oil recovery (EOR) screening criteria described by Taber, Martin, and Seright (1997a, 1997b) with the petroleum and reservoir characteristics (Brown, 1995; May, 1995a; White, 1995; May, 1995b) qualifies these oil and gas fields adjacent to WIPP as potential candidates for future CO_2 flooding. The oil densities for the fields surrounding the WIPP range from 39º to 42º API gravity indicating an abundance of lighter hydrocarbon components for promoting a miscible type displacement. The reservoirs range in depth from 4200 feet to 7100 feet, more than adequate to accommodate the injection pressure required for a CO_2 flood. One obvious limitation is the lack of a local pipeline to bring inexpensive carbon dioxide to these fields. But the major CO_2 pipelines across the state are already in place and recent history has shown that if CO_2 pipelines or facilities are needed, they will be constructed.

The DOE Office of Fossil Energy also recognizes the potential for enhanced oil recovery in the Delaware Basin by carbon dioxide flooding and is sponsoring field research in the Delaware Basin. Specifically, the DOE is funding a study by the Texas Bureau of Economic Geology to couple reservoir characterization with modeling to optimize infill drilling and CO_2 flooding to increase production and prevent the premature abandonment of slope and basin clastic reservoirs (Dutton et al., 1996, 5). The DOE plans to apply the results of studying these two fields to the more than 100 other Delaware Mountain group reservoirs in Texas and New Mexico, which together contain 1.6 billion barrels of remaining oil in place. The compositional simulation of a CO_2 flood in one of the candidate fields has shown that at least 10% of the remaining oil in place can be recovered at breakthrough. The simulation results also show that continuing CO_2 injection beyond breakthrough can result in significant incremental oil recovery, in this case over 30% of the remaining oil in place (Malik, 1998).

Another DOE study of the Brushy Canyon Formation in the Nash Draw fields immediately southwest of the WIPP area also aims to provide information to design enhanced oil recovery operations throughout the Delaware Basin. In addition to obtaining detailed reservoir characterization data for designing an enhanced oil recovery operation, the project also includes the use of a model to "evaluate the technical feasibility and commercial viability of three enhanced recovery processes: waterflooding, lean gas injection, and CO_2 injection" (Murphy, 1997, 26). The investigation is ongoing.

The EPA (U.S. EPA, 1997b, Card 23-132) also relies on the brine injection modeling of Stoelzel and O'Brien (1996) to capture the effects of CO_2 injection. The EPA maintains that the degree of potential anhydrite fracturing by CO_2 "should have been captured by the large volumes of brine and high injection pressures assumed during the brine injection analysis." But as noted above, that analyses is based on an unverified model. Furthermore, the modeling effort is based on the assumption that salt water disposal will potentially cause more problems than fluid injection for enhanced oil recovery because there is less incentive in salt water disposal for the operator to control injection pressures and volumes (U.S. EPA, 1997b, Card 23-132). The assumption invites the obvious question. In New Mexico, why have out of zone waterflows been correlated with waterflood operations and not with salt water disposal wells? For example, in the Hartman vs. Texaco case, it was the Rhodes Yates waterflood operation that was determined to be the culprit and not any of the salt water disposal operations in the vicinity. Hartman produced evidence of very high injection pressures at the waterflood (Van Kirk, 1994; Powers, 1996, 67). In commenting on the history of waterflood problems in New Mexico, Ramey (1995, XI-2) states that water probably escaped from the injection zone and into the salt formations as a result of old improperly cemented and plugged wells and excessive injection pressures in oil field ***waterflood*** operations. There is no mention of salt water disposal operations, the operations that EPA is more concerned about (U.S. EPA, 1997b, Card 23-132). If the concern is excessive injection pressure exerted at the repository horizon in the event of a leak, it seems that waterflood operations would be the most likely concern in the vicinity of the

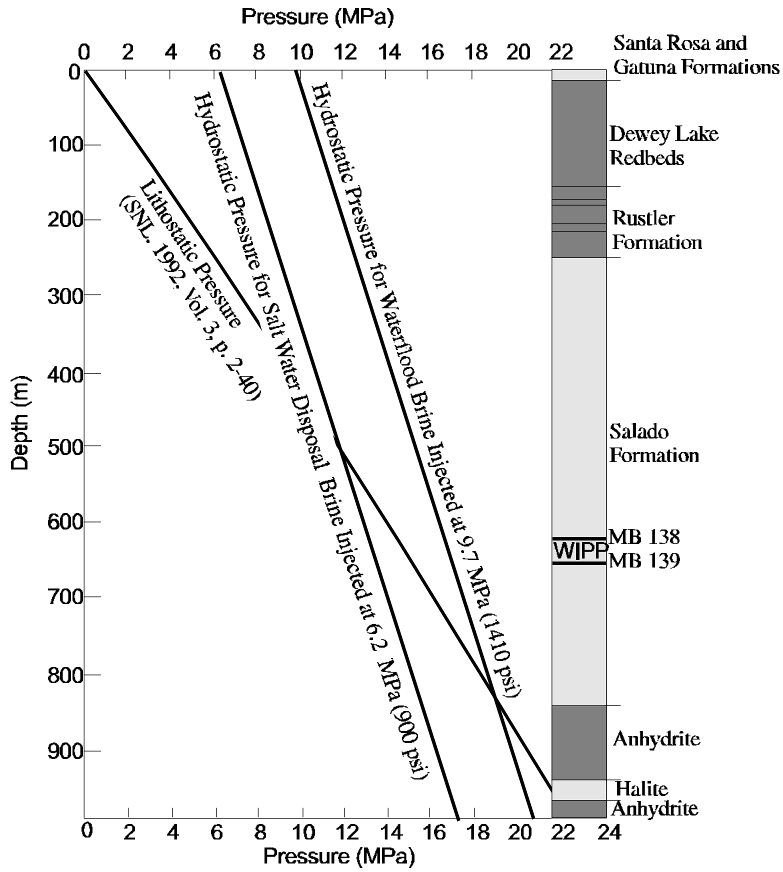

Fig. 19. Comparison of Approved Injection Pressures For Salt Water Disposal Well Versus Oil Field Water Flood Wells Near WIPP.

WIPP. Figure 19 compares the maximum approved disposal pressure for two wells one mile to the east of the WIPP Site. EEG is not suggesting that either of these wells are leaking. But EEG notes that in the event of a leak near WIPP current approved salt water disposal pressures are not sufficient at the repository horizon to exceed the lithostatic pressure. Only the a leak in the waterflood well would be of concern to the repository. This is an inherent result of the greater vertical distance to the oil producing horizons. The DOE and EPA rationale appears to be more appropriate for the more shallow oil and gas reservoirs in the Vacuum Field area and the Rhodes Yates area and not suitable for the WIPP area. Presumably, carbon dioxide for enhanced oil recovery would be injected into the deeper oil producing zones and at sufficient pressures to maintain a miscible displacement. Hence, given the observation above, EPA can not conclude that the salt water disposal well analyses captures the CO_2 flooding scenario.

2.6.6 Rhodes-Yates (Hartman vs. Texaco)

The EPA Technical Support Document acknowledges that the technical evidence related to the case was not reviewed. Rather, the technical support document reviewed a summary of the case. From that summary, the EPA document states:

> Though a jury found the waterflood operator guilty of common law and statutory trespass in the Rhodes-Yates Field, flow paths were not identified with certainty (U.S. EPA, 1997h, vol. 1, p. 31)

But at the EEG fluid injection workshop Powers noted that the flow began at an anhydrite unit on the order of 10 to 15 feet thick. Although he had not tried to correlate it to an individual marker bed, he felt that it was somewhere in the range of marker beds 140 to 142 which are below the WIPP repository horizon (Powers 1996, p. 66). Furthermore, as shown in plaintiff's Exhibit 211 and Van Kirk's testimony (p. 683), the drilling records combined with well logs identified a 36 foot wide zone just above the Cowden Anhydrite Marker as the flow path. If EPA intended to comment on the technical aspects and refer to these comments in the final rule, EPA should have reviewed the technical exhibits and technical testimony of the Rhodes Yates incident.

The EPA discussion on structure can be best described as tentative speculation. The discussion suggests that there might be more flow through possible increased fracturing of the anhydrites ***possibly*** as a result of folding, faulting, or ***perhaps*** salt dissolution which ***might*** be inferred from the varying salt bed thicknesses at the Rhodes Yates Field and the Vacuum Field. The EPA further suggests that water chemistry of the field areas in formations underlying the Salado ***may*** provide evidence of a greater rate of evaporite solution relative to the WIPP Site. But no such evidence is provided. Further, there is no reference to the published literature to support the hypothesis advanced by EPA. In fact, the entire comparison of the geology at the Rhodes Yates, Vacuum, and WIPP areas is filled with statements such as "relatively fresh waters ***may*** have been a contributing factor...", "it is also ***possible*** that fold and dip rates in the vicinity of the other two fields ***may*** contribute to increased fracturing..."(U.S. EPA, 1997h, vol. 1, p. 34). Given the implications of Hartman scenario at WIPP, it is unclear how EPA's geologic analysis can be considered as adequate to support an EPA conclusion that a repeat of the Hartman scenario is unlikely at WIPP.

2.6.7 Culebra Water Level Rises

EEG remains concerned that there is no explanation for ten years of anomalous water level rises in the Culebra Aquifer. The water level rises began suddenly in April, 1988 (Beauheim, 1990). LaVenue (1991) conducted an investigation that raised serious questions about oil field operations. In a memo to LaVenue, Bailey (1990) identified an old salt water disposal well as the most likely source of the problem. LaVenue also explored the possibility of modelling the change in the aquifer. He found that his model could very nearly match the observed water level rises if he assumed that nearly all of the water from the salt water disposal well was entering into the Culebra (Beauheim, 1996). Beauheim (1996, 40) had also concluded that the water level rises were most likely due to some well effect. EEG-55 (Silva, 1994) had commented on the issue suggesting that leakage of oil, gas, or salt water injection wells in the Delaware Basin may have an impact on the regional hydrology. In response to the EEG report, DOE stated:

> There is currently no credible evidence that the observed water level increases can be directly or indirectly linked to activities in the WIPP area initiated by the petroleum industry. The mechanism that resulted in these water level rises have not been identified, one can only speculate as to their cause (McFadden, 1996, 11).

With respect to this issue, EPA told DOE:

> 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 (Trovato, 1996).

Silva (1996, 125) found that a comparison of the injection history of the salt water disposal well and the water level rises at H-9 strongly suggested communication between the injection well and the Culebra Aquifer. The DOE still has not submitted an explanation of the water level rises to the EPA and EPA does not appear to require one for the certification of the repository. In addition to the questions raised in EEG-62, if the modelling results (LaVenue, 1991; Beauheim, 1996) of the water level rises are consistent with a well injecting large quantities of water out of zone and DOE has not been able to find the source of the water, how much credit can DOE or EPA claim for the reliability of the Underground Injection Controls program? The 1996 NRC WIPP Committee report also expressed concern about the unexplained water level rises:

> An adequate explanation is lacking for observed changes in water level in the Culebra, where trends of rising water levels have persisted for several years. Observed changes in water levels from assumed steady-state conditions were not incorporated into the 1992 PA analysis. However, if the causes of the observed water level changes during the last several years are unknown, then how is it to be known that even greater changes in the flow field might not occur in the near future? Such changes might invalidate the PA assumptions and predictions (NRC, 1996, pp. 69-70).

2.6.8 Brine Production

As noted by EPA (U.S. EPA, 1997b, Card 32-10), and identified by EEG at the EPA technical exchange on 10/10/96, the CCA did not address the practice of solution mining of halite for use as brine in the drilling industry. The CCA specifically stated:

> The DOE is not aware of solution mining for potash or other minerals in the Salado within the Delaware Basin at this time (U.S. DOE, 1996c, MASS-87).

The EEG identified seventeen active brine production facilities removing halite from the Salado Formation, three of which were in the Delaware Basin (BW-6, BW-19, and BW-27). EPA notes that Appendix DEL identified a dissolution project approximately 14 miles from the WIPP. Furthermore, EPA notes that DOE submitted additional information which showed that brine production between

1979 and 1991 created a cavity of 3.4 million cubic feet and that it would be longer than 50 years before subsidence would occur.

As shown in Figure 20, there are three solution mining operations for brine production near the city of Carlsbad area and at least 16 miles from the WIPP site. EPA mentions only one about 14 miles from the WIPP Site. Furthermore, EPA does not discuss the trend towards drilling brine production facilities closer to WIPP. Brine well BW-26 has been approved for production from the Salado Formation. The solution mining operation would be located between Jal and Carlsbad to meet the demand for drilling brine. The well was approved to remove salt from the Salado formation which lies between 1500 to 2300 feet deep. The subsidence calculations provided by DOE were for a facility that is 583 feet deep.

Solution mining of the Salado Formation is an important observation. It is important for EPA to

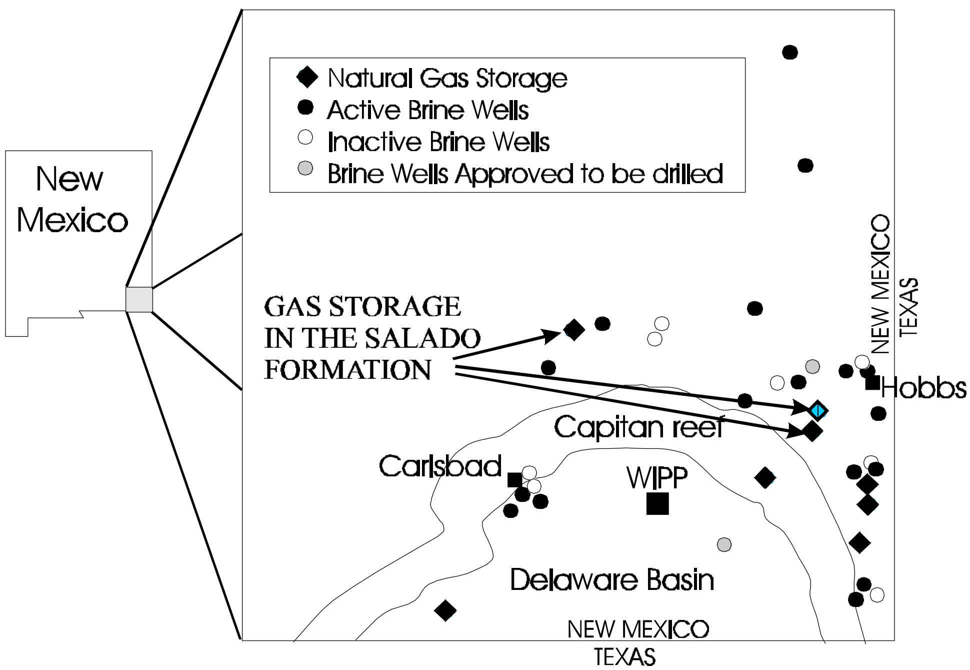

Fig. 20. Solution Mining of Brine and Natural Gas Storage Wells.

demonstrate a very clear understanding of the current situation and the full issue in the final rule.

2.6.9 Natural Gas Storage

EPA maintains that “there are no natural gas storage horizons in the Salado Formation” (U.S. EPA, 1997b, Card 32-71). As shown on a map presented to EPA by EEG on October 10, 1996, there are eight gas storage underground facilities in southeast New Mexico, three of which are in the Salado Formation in which the salt was “washed out to create a cavern.” Furthermore, the natural gas storage wells can not be dismissed with a statement that they are not in the Delaware Basin. Successful operation of these three facilities for the last four decades has shown that the Salado Formation is conducive to gas storage facilities and it can be anticipated that oil and gas production will continue to increase in the Delaware Basin.

2.7 ANHYDRITE FRACTURE MODEL

2.7.1 Introduction

Criticisms of the anhydrite fracture model used in the BRAGFLO code have been brought to EPA's attention by Walter Gerstle and John Bredehoeft (Gerstle, 1996, Bredehoeft, 1997c; Bredehoeft and Gerstle, 1997; Gerstle and Bredehoeft, 1997). On March 19, 1997 the EPA requested that the DOE provide additional material describing the development of the anhydrite model beyond that supplied in the CCA documentation. As EEG pointed out during a December 10, 1997, meeting with EPA, this additional documentation indicates that the anhydrite fracture model used in BRAGFLO was intended to mimic the LEFM model developed by Gerstle et al. (Gerstle et al., 1996), but fails to do so.

On September 16, 1997, the DOE sent a letter to the EPA criticizing the LEFM model (Dials, 1997b). The EEG found this letter referred to the opinions of Sandia scientists and contained numerous misleading statements, yet lacked any substantial arguments against the LEFM model.

The EEG has reviewed the basis of the anhydrite fracture model used in the BRAGFLO code and has a number of questions about its validity. The model is unusual in that effect of fracturing is treated using an equivalent porous medium. All the relevant literature that we have examined treat fractures as distinct porosity. Use of an equivalent porous medium is not in itself unreasonable. However, the DOE has not referenced, nor have we been able to find, a description of similar treatment of the dependance of porosity and permeability on pressure as a result of fracturing. The lack of a clear development of the BRAGFLO model from established models makes its review difficult. The EPA should request that the anhydrite fracture model of BRAGFLO be compared to the treatment of fracture development in hydrofracing codes commonly used in the industry.

2.7.2 Questionable Assumptions in the BRAGFLO Model

The BRAGFLO model has been developed using several assumptions that are questionable. The following is a description of each of these questionable assumptions

The first assumption is that anhydrite will fail along planes of weakness that are probably pre-existing fractures. Hydrofracing experiments at WIPP indicated a large permeability increase when the fluid pressure reached the estimated confining stress in some instances (Wawersik et al., 1997). Other hydrofrac experiments at WIPP showed that the anhydrite remained unfractured at pressures which exceeded the confining stress by seven MPa. The BRAGFLO model assumes that hydrofracing will occur at the lower pressures and build up local stresses to cause the other regions to fail as well. While weakness dominated fracture development is probably a reasonable assumption it is not certain. Walter Gerstle believes that the pre-existing anhydrite fractures are healed by salt precipitation (Gerstle, 1998). It is entirely possible that the strength of healed fractures was reduced by local stress changes induced by the proximity of the repository to the fracture tests. This conceptual model uncertainty is not represented in the CCA calculations.

Another major assumption of the BRAGFLO model is that the porosity and permeability will increase at pressures below the lithostatic confining stress. Laboratory investigations of the permeability of fractured rocks support this assumption for existing fractures (Raven and Gale, 1985; Pyrak-Nolte et al., 1987; Cook et al., 1990). Increased permeability of the fracture over intact rock was evident and sensitive to pressure even at the highest confining pressures, 20-40 MPa. Fracture permeability increased 3 to 5 orders of magnitude as the confining stress was reduced to near zero. Note that the BRAGFLO model represents conditions of greater than lithostatic stress, so permeability increases of more than 5 orders of magnitude are possible. At pore pressures greater than lithostatic, confining stress in maintained by deflection of the rocks above the fracture.

The laboratory experiments also support the concept of permeability increasing at a rate greater than implied by the cubic law of parallel plate fractures. The steepest increase reported is an exponent of roughly nine which is considerably less than the exponent used in BRAGFLO. However, the permeability dependance on aperture becomes cubic as the aperture increases. Cook et al. (1990) have fit their experimental data to a simple model that includes the effects of tortuosity on effective permeability. The model indicates that the relationship becomes cubic for apertures in excess of 10^{-4} m. The estimated fracture aperture in the hydrofrac experiments was estimated to be on the order of 5×10^{-3} m (Wawersik et al., 1997) and the BRAGFLO model is intended to represent effective apertures up to 10^{-2} m (Larson, 1996).

If one takes 10^{-4} m as the effective aperture for a fracture in contact, then a total permeability increase of nine orders of magnitude is reasonable for an effective aperture of 10^{-2} m, but the greater than cubic law dependance of permeability on porosity is not. Raven and Gale (1985) found fracture permeability became dependent on the cubic of aperture in the laboratory experiments at total confining stresses of less than 1 MPa.

The assumption of multiple anastomosing fractures complicates the comparison of laboratory experiments on single fractures and the BRAGFLO model. The experimental support for multiple fractures comes from examination of core recovered from the hydrofracing experiments (Wawersik et al., 1997). Some of the core showed evidence of multiple flow channels for the tracer dye used in the experiments. This evidence supports the notion of a few channels but not the hundreds to thousands of fractures required to reduce individual fracture apertures below 10^{-4} m. The notion of many fractures of small aperture is also inconsistent with the nine orders of magnitude range of permeability change.

The laboratory experiments also support the concept of reduced fracture stiffness (increased compressibility) with increasing pore pressure. We have not attempted to determine whether a linear change is reasonable. Below lithostatic pore pressures, stiffness may be a combination of stiffness of the fracture contact zones and stiffness of the host rock with respect to both compression and bending. At pore pressures above lithostatic, confining stress is due to deflection of the fracture faces and resulting bending of the host rock. Given the relatively small deflections of the fracture faces, it seems reasonable to expect that stiffness becomes constant above lithostatic pore pressures.

2.7.3 Summary

In summary, laboratory experiments on individual fractures support the assumptions used to formulate the permeability-porosity relationship of BRAGFLO anhydrite fracture model, but these experiments also strongly indicate that the model is only applicable at pore pressures more than 1 MPa below the lithostatic pressure. Above this pressure threshold the conventional cubic law model applies to the relationship of permeability and porosity. However, the exponent used in the BRAGFLO model is much larger than can be supported using experimental evidence.

The laboratory evidence also supports the concept of increased compressibility with pore pressure. It does not seem reasonable for compressibility to increase with pore pressure above the lithostatic pressure.

2.7.4 Conclusion

Our conclusion is that the conceptual model BRAGFLO for anhydrite fracturing may be a valid description for pore pressures less than 1 MPa below lithostatic but a cubic law formulation of the permeability-porosity relationship is valid above this threshold. As demonstrated by Freeze et al. (1995), the BRAGFLO parameters can not be set to reasonably represent this region. Figure 21 is an updated version of Figure 2 of Freeze et al. (1995). The BRAGFLO model is based on CCA parameters for marker bed 139 and anhydrite layers A and B respectively. The figure shows the permeability-porosity relationship of the BRAGFLO model to a cubic law based model for multiple fractures. Our concern is that the BRAGFLO model under-represents permeability by more than four orders of magnitude for small porosity increases. By setting the model parameters to match a cubic law fracture model at large .porosity, a large error may have been introduced for small porosity changes.

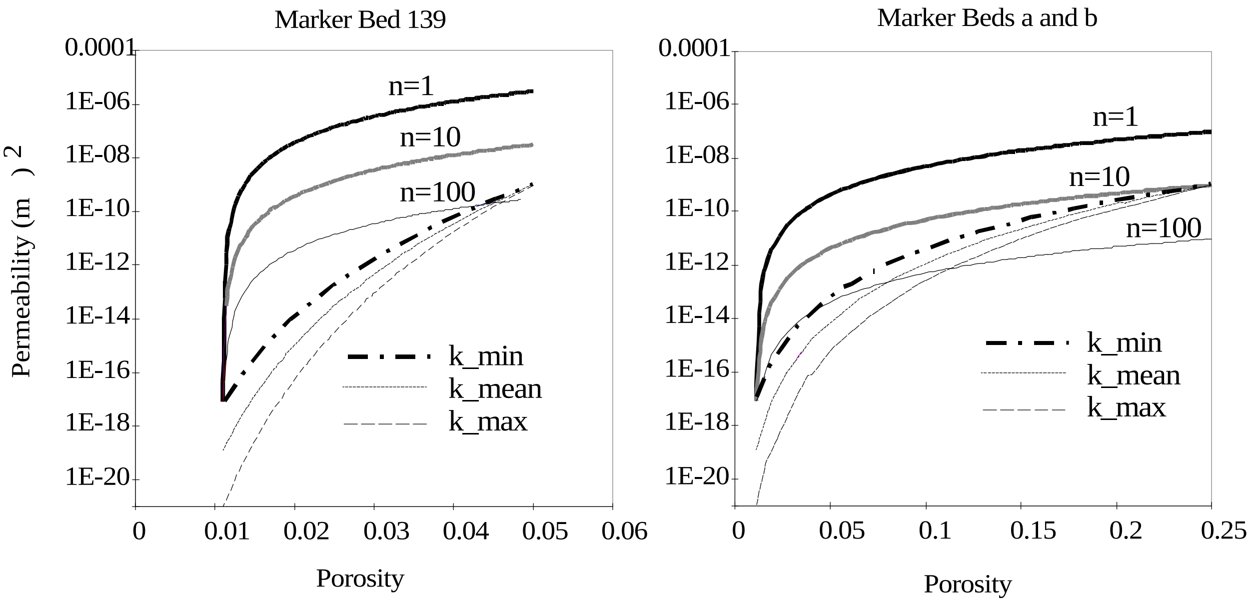

Fig. 21. Permeability vs. Porosity Model With BRAGFLO for Left) Marker Bed 139 and Right) Marker Beds a and b.

The BRAGFLO model has not been tested against either laboratory or hydrofracing experiments or other standard fracture modeling codes. This comparison should be made before the model can be accepted as valid.

A meeting was held pn February 17, 1998 to try to resolve this issue. Participants included scientists from Sandia National Laboratories; EEG; Dr. Charles Fairhurst and Dr. Jim Tracy, DOE consultants; and other DOE consultants. Dr. Walter Gerstle sent a letter to the EEG after the meeting, commenting on some of the presentations. The EEG invited the DOE to allow us to include in this report the viewgraphs used by the SNL presenters and comments on the meeting, but the DOE declined this invitation. Dr. Gerstle's letter is included as Appendix 8.7 to this report.

2.8 SOLUTION MINING AT THE WIPP

The final rule of the EPA for the certification of the WIPP requires the DOE to consider the effects of mining in performance assessments (U.S. EPA, 1996). However, the analyses need only consider the effects of the excavation mining of high grade ores, ores which are currently economical, and which are known to be present near the WIPP site, but which are known not to occur vertically above the repository. The effects of mining for low grade ores, ores which are currently uneconomical, and which could be present below or above the formation containing the high grade ores, need not be considered once the high grade ores have been removed.

The effect of excavation mining is subsidence of the overlying formations and the potential alterations of their hydrologic properties. The most important hydrogeologic unit overlying the repository is the Culebra aquifer. Therefore, in the performance assessments of mining effects, EPA permits the DOE to limit the analysis to changes in the hydraulic conductivity of the Culebra aquifer.

The EPA initially concluded that solution mining of potash is currently not feasible in the Delaware Basin (Peake, 1996). EEG (Neill, 1997a) identified solution mining as a potential scenario that must be considered by the WIPP project. In response to the concerns raised by EEG, Dials (1997d) submitted to EPA materials solicited from Heyn (1997a) and Hicks (1997). Based on the supplemental information provided by DOE, EPA maintains that changes in the hydraulic conductivity as a result of solution mining are captured in the modeled effects of room and pillar mining, that solution mining is not likely in the vicinity of WIPP because fresh water for mining is limited and the overall procedure is cost prohibitive, and that langbeinite is the primary target of extraction and is not readily soluble in water (U.S. EPA, 1997b, CARD 32-55).

The supplemental materials that DOE submitted to EPA are based directly (Heyn 1997a) and indirectly (Hicks 1997) on solicited comments from the Chief Chemist for IMC-Kalium. The comments must be viewed with caution. Heyn (1997a) makes no references to the scientific literature. With respect to the lack of fresh water for solution mining:

> Solution mining requires access to large quantities of water. As you know, fresh water is a difficult and expensive commodity to come by in this corner of New Mexico. Water rights carry a premium price if they can be obtained at all. I would rather think the agricultural uses would have a far more beneficial use rather than solution mining (Heyn, 1997a).

Records on file with the New Mexico State Engineer indicate that on April 22, 1994, IMC Fertilizer (later IMC-Kalium) purchased 2790 acre feet per annum from Noranda Exploration (Files L-7121, L-7121-S, L-7157, L-7157-S). On November 6, 1996, IMC-Kalium, acquired an additional 2014 acre feet of water per annum to be produced from the Ogallala aquifer and piped to IMC's potash mining and refining operations (Files L-10,580, L-10581, L-10582, L-10583, L-10584, L-10584-S). It appears water rights for mining of potash ore and other related purposes can be obtained in southeast New Mexico, a detail apparently not brought to EPA's attention.

EPA maintains that the overall procedure is cost prohibitive. Heyn argued that the building of any potash mine, refinery and auxiliary facilities would require a capital investment in excess of 100 million dollars and that such an investment would require reserves in excess of 25 years. The argument provides no supporting economic calculations and no estimates of potash reserves. However, in a letter to EPA Heyn acknowledges that he is "not an expert on the extent and grade of ore reserve on the WIPP site" (Heyn, 1997b).

Heyn also suggests that efficient solution mining requires great depths to take advantage of geothermal energy such as at IMC's solution mine at Belle Plains, Saskatchewan. That mine is in excess of 3000 feet deep. Heyn comments that the potash bearing zones are only 650 to 800 feet below the surface at the WIPP site. Actually, the potash bearing zones in the vicinity of WIPP are at depths between 1400 and 1750 feet (Chaturvedi, 1984, Figure 1). Nonetheless, even at a depth of only 1150 feet, Davis and Shock (1970, p. 109) determined that a production operation would yield 90 pounds of ore for every barrel of water injected for a potash ore zone in the Carlsbad Potash District strongly suggesting that a solution mining operation does not require the depths cited by Heyn (1997a, 1997b).

Heyn (1997a) maintains that solution mines would prefer ore bed depths to be thick, in excess of 10 feet or more to minimize solvating of unwanted minerals and displacement of clay in solubles. Yet Conoco conducted its successful field trial for solution mining of thin bedded potash on an ore zone that was 4 feet thick (Shock and Davis, 1970). In carefully designed two well test, Conoco produced 1600 tons of sylvite (KCl) and 9600 tons of halite (NaCl). And 1500 tons of that halite was produced in a final injection designed to confirm that all of the sylvite ore had been produced. If Conoco had stopped at the previous step, as would be anticipated for actual operating conditions, the total production would have been 1450 tons of sylvite and 8100 tons of halite.

In 1995, the New Mexico Bureau of Mines and Mineral Resources examined future potash mining techniques and concluded that solution mining is the only method that can be reasonably predicted for the Carlsbad District for the far future. The report notes that while no specific plans have yet been formulated, all mines in the Carlsbad area have held open the option of using solution mining once their sylvite deposits are fully mined out (Broadhead et al., 1995, p. IV-5). It is the remaining sylvite pillars, not langbeinite, that would be the primary target for solution mining.

EPA has accepted that changes in the hydraulic conductivity of the overlying Culebra Aquifer as a result of solution mining are captured in the modeled effects of room and pillar mining. The prediction of the subsidence of the ground above solution mines can be a much more complex problem than the prediction of the subsidence of the ground above conventional or excavation mines. There are verified analytical methods and formulae to predict the subsidence of the ground above excavation mines. The subject is treated in great detail in the textbook of Jeremic (Jeremic, 1994). The subsidence of the ground can be illustrated as a crater. The subsidence is uniform over the mined area with gentle slopes over the boundaries of the mined areas. In contrast, the solution mining of sodium chloride has lead to the formation of large caverns, some of which have resulted in the collapse of the overlying sediments and the appearance of large sink holes. As an example, three spectacular sink holes occurred in 1954 over a solution mine for sodium chloride at Grosse Ile in Michigan (Jeremic, 1994). Non-uniform sinking of the ground has also been observed in Tusla, Bosnia (a former province of Yugoslavia), a town where uncontrolled solution mining of sodium chloride has been practiced for over a century.

2.8.1 Potash Solution Mining

Forty years ago, one could argue that solution mining was not used for potash, therefore it will never be feasible. The solution mining of potash is a young technology. It was started in Canada in the mid 1960's. The solution mining of sodium chloride is a very old technology. There are indications that the solution mining of sodium chloride was practiced as early as 1147AD in the small town of Altaussee, Austria (Gaisbauer, 1997).

The solution mining of potash is significantly different from the solution mining of sodium chloride. For one thing, the size of the literature on the solution mining of potash is small compared to that on the solution mining of sodium chloride, which is very large. The situation was described in 1983 as follows (Diamon, 1985): “There is a scarcity of published material on in situ potash leaching. Only a few studies have been carried out. For competitive reasons, companies involved in solution mining of potash or have an interest in getting involved, generally don’t publish their findings.”

Chemically, the solution mining of potash is significantly different from the solution mining of sodium chloride. The solution mining of potash is complex and carried out with brines. Considerations must be given to the following parameters: 1) the equilibrium system of the solubility of many salts in water; 2) the temperature of the brine in the mine; and 3) the processing of the saturated brine to achieve preferential precipitation at the surface. In contrast, the solution mining of sodium chloride requires only fresh water. Currently, solution mining of sodium chloride is used primarily to create large storage caverns for oil and natural gas.

Some have argued that solution mining of potash more economical than conventional or excavation mining of potash. IMC Kalium is currently expanding the annual production of its solution mining operation at Hersey, Michigan, from 50,000 to 150,000 short tons at a cost of $43 million (IMC, 1996). Such a large investment indicates that production of potash by solution mining in Michigan enjoys strong economic advantages over shipments of potash from Canada or the Carlsbad area. The following statement with regards to economical considerations is made in a publication (Gruschow, 1992): "therefore instead of waiting until an opportunity arises to repair or improve a conventional potash mining operation by conversion to solution mining, potential potash ore mining projects should be designed from the very beginning as solution mining operation."

There are four solution mining operations in North America. Two are in Canada and the other two are in the United States. A large potash solution mine is being operated by IMC Kalium at Belle Plain, Saskatchewan, Canada. The operation was started in the mid 1960's and in 1982 it had an estimated capacity of 940,000 ton per years (Nigbor, 1982). The mine extracts potash from depth where shaft mining is very difficult and hazardous. There are no publications describing all the changes that must have occurred to keep the operation going for about 30 years. The second Canadian solution mining operation is in the Patience Lake area, Saskatchewan, Canada. The mine is currently owned by The Potash Corporation of Saskatchewan, Inc. The mine was started as an excavation mine in the late 1950's, but it had to be converted to a solution mine in 1987 due to large inflow of water. A detailed description of the conversion from an excavation mine to a solution mine has been published (Smith, 1990). In the Canadian mines, potash is precipitated in crystallizers, which is possible because of cold temperatures.

The oldest solution mine operation in the United States is located in Moab, Utah. It is now owned by Potash Corporation of Saskatchewan, Inc. The mine was started as an excavation mine in 1964. The highly folded and distorted nature of the ore zone made mining difficult and largely unprofitable. The mine was converted to a solution mine operation in 1970 and production of potash began in 1972. A detailed description of the conversion from an excavation mine to a solution mine has been published (Jackson, 1973). The Moab mine uses solar energy to precipitate the potash in a 400 acre evaporation pond. In 1973, the operation was expected to produce 300,000 ton per year for 20 years. Many changes must have occurred since the mining operation is still active. The second solution mine operation in the United States is operated by IMC Kalium at Hersey Michigan. The operation appears to have been started in the mid 1980's (Shock, 1985) and as already indicated, its annual production is currently being expanded to 160,000 short ton per year.

A few research studies have been published. There are two papers on an early solution mining test in the Delaware Basin (Shock and Davis, 1970; Davis and Shock, 1970). The project was not pursued because the price of potash was depressed at that time (Davis and Shock, 1970). Plans for pilot scale testing in the Montana North Dakota area were drawn up in the late 1970's (Nigbor, 1982), but it does not appear that these plans were carried out.

Solution mining of potash has been considered outside of North America. A test facility appears to have been operated at the Potasio Rio Colorado deposits in the Argentine (Colome and Ruse, 1994). Considerations were given once to the solution mining of potash from carnallite in what was East Germany (Duchrow, 1990). It should be mentioned also that Israel and Jordan extract economically about 2.1 million ton of potash from brines of the Dead Sea using large solar evaporation ponds (about 9% of the world production of potash). The KCl of these Brines is only 1% (12g/l), which is considered to be low (Gruschow, 1992).

Solution mining of potash has been successful in the operation of four converted excavation mines in North America. Two mines have operated for about 30 years and the other two for about 10 years. Solution mining is being considered for the Eddy potash mine in the Carlsbad area. The owner ceased excavation mining activities on December 3, 1997 (Davis, 1997) because the mine had been depleted of high grade ores. However, high grade ores, which remain in the pillars of the mine, can only be removed by solution mining. EPA notes that a permit is being sought for a commercial pilot solution mining venture in the Carlsbad area but EPA characterizes the proposed solution mine as speculative because it is not being done and may not take place (U.S. EPA, 1997b, Card 32-55). One might be reminded that a permit is being sought for a federal pilot waste disposal venture in the Carlsbad area, an activity that is also not being done.

Finally, one must consider that if that extensive oil and gas development continues to expand in the potash portion of the Delaware Basin, the safe and economical production of residual potash may require solution mining.

2.8.2 Probability of Mining for Potash at the WIPP Site.

The EPA derives the mining probability of 1 in 100 in each century of the regulatory time frame using the following assumptions (Peake, 1996): 1) the mining rate in the Carlsbad area in the future will be the same as in the past; 2) the mining of different potash ore zones near Carlsbad has covered an area of 40 square miles in 62 years (1931 to 1993); and 3) future mining of potash can occur in the entire Delaware Basin, which covers an area of 9700 square miles.

The mining rate in percentage per century is

$$(40/9700)*(100/62)*100\% = 0.67\%$$

This value is then rounded upward to 1% and called a mining probability of 1 in 100 in each century of the regulatory time frame.

The assumption that a mining rate can be called a probability is technically incorrect. The EPA should have stated that it is assumed that the mining at a particular site in a century is governed by a Poisson distribution with a rate of 6.7 E-05/yr. The probability of no mining occurring at a particular site in a century is then given by

$$P(\text{no mining in a century}) = e^{-(6.7E-05*100)} = 0.9933$$

and the probability of mining occurring at least once in a century is

(Mining at least once in a century) = $1 - e^{-(6.7E-05*100)} = 0.0067$

which can be rounded upward to 0.01 or 1%.

Note that the probability for mining occurring at least once during the regulatory time frame of 100 centuries is given by

P(mining at least once in 100 centuries) = $1 - e^{-(6.7E-05*10,000)} = 0.49$

for a mining rate of 6.5E-05/yr and

P(mining at least once in 100 centuries) = $1 - e^{-(1.0E-04*10,000)} = 0.63$

for a mining rate of 1%/century.

It would be shortsighted to assume that the mining of potash in the future will be comparable to the past, which was based on past mineral economics. Modern agriculture depends on nitrogen based fertilizers and almost all the mined potash is mixed with fertilizers. It has been estimated that about 40 percent of the world population is alive because of the use of nitrogen based fertilizers (Smil, 1997). World reserves for high grade ore of potash have been estimated at 8.4 million tons (Searls, 1996). Reserves for Canada and the United States (mostly in the Carlsbad area) have been estimated at 4.4 billion toms and 76 million tons respectively. World production of potash peaked in 1987 at an annual production of 30 million tons of K_2O and then dropped sharply to an annual production of 20 million ton by 1990 (Searls, 1995). Production has fluctuated but increased to 24.3 and 22.9 million tons in 1995 and 1996 (Searls, 1997). Rayrock Yellowknife Resource Inc, a company that mines for potash in the Carlsbad area, reported in 1996 a 6.1% increase in the finished product of langbeinite from 379,100 to 402,400 tons (Rayrock, 1996). Rayrock Yellowknife Resource states also that it has approximately 21 years of remaining reserves in Nash draw. IMC Kalium, a large producer of potash that also operates a mine in the Carlsbad area, indicates that China will have to increase its potash consumption by the year 2,000 to 7 million tons of K_2O in order to optimize its food production. The 1996 consumption of K_2O in China was 3 million tons (IMC, 1996).

These statistics indicate that the world reserves of high grade potash ores will be depleted in about three centuries, which is very short compared to the regulatory time frame of 100 centuries.

The economic considerations of potash offer two scenarios for consideration:

> 1) low grade potash ores such as occur over the WIPP site will become economical and will be mined. The probability of the mining of potash over the WIPP will be certain or 1.0;
>
> 2) the world population will decrease sharply eliminating the need for large quantities of fertilizer. The probability of the mining of potash at the WIPP site will be much less than 1.0.

The former scenario appears to be far more reasonable.

2.8.3 Conclusions

1. EPA's conclusion that potash solution mining is not likely at WIPP relies on solicited comments that are factually incorrect and inconsistent with the published scientific literature.

2. DOE and EPA maintain that excavation mining captures the effects of solution mining on the hydraulic conductivity of the overlying aquifers. However, based on the scientific literature, the prediction of subsidence above solution mines can be much more complex than the prediction of subsidence due to excavation mining. This issue needs to be reevaluated for the final rule for WIPP.

3. Potash is a resource used for the production of food, therefore it appears to be incorrect to calculate a probability of mining based on past potash production which was inherently dependent on past mineral economics and the availability of high grade ore. It also seems reasonable to assume that low grade potash ores will eventually be mined to meet world demand.

2.9 GROUNDWATER FLOW AND RADIONUCLIDE TRANSPORT THROUGH THE CULEBRA

2.9.1 Introduction

The proposed rule (U.S. EPA, 1997c, p. 58799) discusses the causes for the lack of contributions to the total releases from the ground-water pathway, concludes that this was due to the assumed values for chemical retardation (K_d), and finds the K_d values used in the calculations to be reasonable except the lognormal distribution. As a matter of fact, the very low contribution of the releases from the ground-water pathway is 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 (NRC, 1996; Chapter 6 and Appendix F) raised a number of issues regarding the conceptual model and numerical model of transport through the Culebra aquifer. Only some of these issues have been addressed in the proposed rule, and even those in a very cursory fashion. The EPA's Technical Support Document III-B-6, Sections 1.3.18 and 1.3.19, discuss the issues related to Culebra transport, but do not question the DOE assumptions and modeling. The responses to comments on the issue of "Ground-water Flow and Radionuclide Transport in the Culebra" are contained in the CARD 23, pages 127 to 133, but do not discuss most of the issues raised by the NAS WIPP Committee. Several of these issues were also presented by Dr. Leonard Konikow at the EPA/DOE meeting on December 5,6,7, 1995, in Carlsbad NM; and at a meeting of the NAS WIPP Committee's sub panel on Hydrology at the Sandia National Laboratory on February 10 and 11, 1997. Because of the lack of adequate consideration by the EPA, as seen in the "proposed rule" documents, the EEG requested Dr. Konikow to provide a summary of the issues that he has raised but remain unresolved. The following is based on personal communication from Dr. Konikow (Konikow, 1998).

2.9.2 Transport Calculations

Heterogeneity and Model Discretization: Much recent hydrogeologic research has clarified the importance of heterogeneity in controlling solute transport. What constitutes an adequate scale of definition of formation heterogeneity for a flow model may be inadequate for solving the transport equation in the same formation. Konikow (1997) presented results of numerical experiments indicating that the CCA consistently underpredicted the migration distance of a plume emanating from a human intrusion borehole. In the CCA model of the Culebra, it appears that errors arising from several sources cause an artificial spreading of the calculated width of the plume at the expense of its length. The sources of these errors include: numerical dispersion and spatial truncation errors in the transport code, poor resolution from using a grid that is too coarse for the scale of the problem, and overestimates of the size of the solute source area. The resulting nature of these errors is illustrated in Figure 22, in which plume shapes are simplified to occur as a triangle; also, for simplification, concentrations are assumed to be uniform and equal within the plume, and zero outside of the plume. Then, if the plume spreads out laterally more than would actually occur, for a given mass of contaminant released from a leaky borehole, the wider plume (a) will necessarily move downgradient a shorter distance than the narrower plume (b). Both plumes in Fig. 22 enclose identical surface areas, so they would encompass equal volumes of aquifer and equal masses of contaminants.

The solute-transport model used in the CCA is based on a finite-difference grid having a minimum spacing of 50 m. An alternative analysis was performed using the MOC3D model (Konikow et al., 1996) in which the transmissivity variations are represented on a much smaller scale, using a 2-m grid spacing, rather than the original 50-m grid spacing. This finer-scale representation of the heterogeneity and of the borehole source area results in a much longer, but narrower, plume that would have a significantly shorter travel time to the regulatory boundary for equivalent concentration levels. The 50-m discretization and related approximations, in effect, could bias the calculations toward demonstrating safety because plumes calculated using the coarser grid would not travel as far towards the regulatory boundary in 10,000 years as they would with a finer grid.

Heterogeneity of Other Transport Parameters and Processes: The CCA model of the Culebra assumes that most properties of the system, except the transmissivity, are homogeneous and uniform within each simulation realization, but that these properties varied from run to run. Field

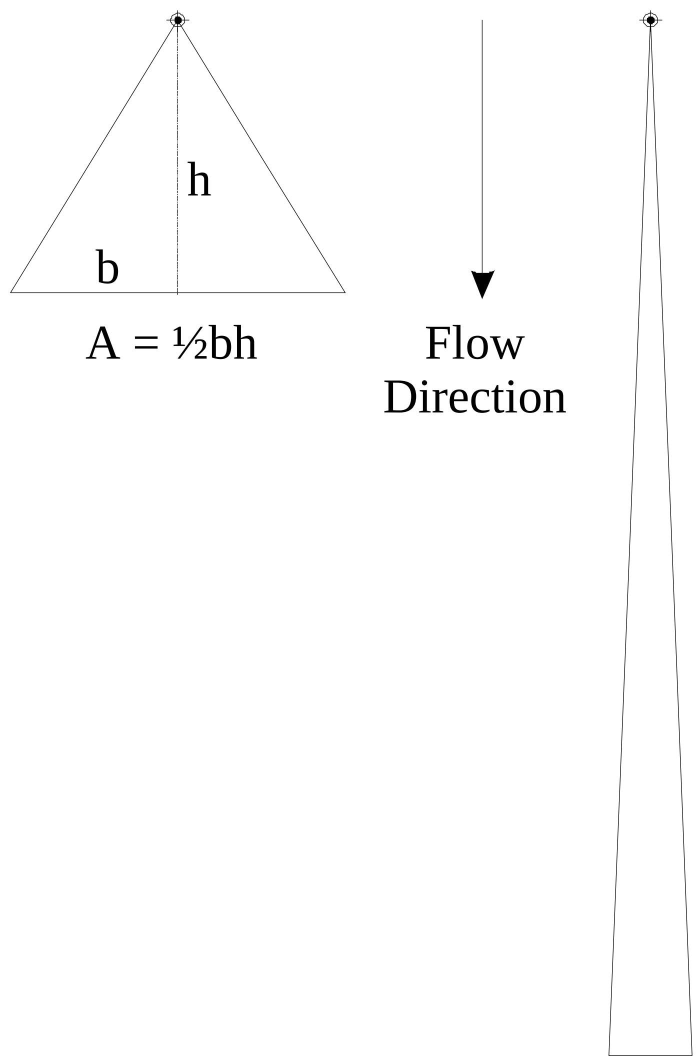

Fig. 22. Conceptual Diagram Of Contaminant Plumes Represented As Simple Triangles, Showing Different Travel Distances For A Relatively Wide Plume Compared To That Of A Relatively Narrow Plume, Where Both Plumes Encompass Equal Volumes Of Fluid And Equal Masses Of Solute.

tests at WIPP, however, indicate significant variability in many of these properties. For example, the effective porosity of the aquifer varies by almost an order of magnitude, even over a distance of only 50 m (the size of one cell of the model grid). Porosity has a strong control on transport velocities and times. Hence, the variability in porosity induces variability in velocity, which means that some parts of the plume may move faster than the local average velocity. This effect cannot be captured by assuming that porosity is uniform in each simulation. One would expect other properties, such as K_d and fracture spacing, to similarly exhibit large spatial variations. The PA procedure inherently assumes that heterogeneity in these variables has no significant impact on transport, or that its effects can be adequately represented by varying uniform properties among all the realizations. Either way, the CCA has not demonstrated that this is indeed the case and that it is reasonable to ignore the spatial variability in all of these critical parameters.

Sampling Procedures for Input Parameters: To generate the statistical distributions from which the risks are calculated, many simulations of hydrogeologic processes are performed to generate an adequate sample size. The approach to varying the values of the many parameters in the multiple realizations can introduce errors into the final analysis. In particular, if hydrogeologic variables that are highly correlated are sampled independently, and if the correlations are ignored, then some of the realizations may be based on unreasonable or very unlikely combinations of parameters; such individual simulations should not be incorporated into the final analysis because they may skew the statistical results. This was the basis for a criticism of the WIPP performance assessment by the NAS WIPP Committee (NRC, 1996, p. 71). For example, the CCA separately sampled and independently varied aquifer transmissivity, fracture spacing, and porosity. Yet there is good reason to suspect that these variables are interrelated.

The significance of this problem can be illustrated with a relatively simple example. Suppose that a strong positive correlation exists between two critical model parameters, as represented in Fig.23a, and that all data points will fall within the indicated bounds. Furthermore, assume that a safety failure for the geologic repository will only occur if the values for both parameters are very high, as represented in Fig. 23a. If the sampling procedure generates values independently for both parameters from uniform distributions for a sample size of 25, for example, then we might expect the 25 realizations to be based on parameter values distributed uniformly in the sample space, as represented in Figure 23b. That is, we would expect a plot of joint values of the two parameters to yield one point in each of the 25 squares in the grid shown in Figure 23b. Only one of the 25 realizations (representing the value in the upper right corner of the grid) will yield a failure, and the probability of failure on this basis will appear to be 0.04. Twelve of the samples, however, were obtained from outside of the bounds of the feasible set of values. If these are discarded, as they should be, then the failure probability is only one out of 13 (or about 0.077), or nearly twice as great as indicated by independent sampling that ignores the correlation between these two variables. The net effect of the independent sampling approach in this example of correlated parameters is to "pad" the outcome with "safe" cases (or realizations), thereby yielding a biased risk assessment.

Consistency Between Performance Assessment (PA) Models: The PA procedure uses one model to calculate the fluid and solute flux up and out of a Human Intrusion (HI) borehole. This outflow flux should then be equal to the input flux (source term) in the Culebra model that is used to calculate transport distances and times. However, the source term in the Culebra model is apparently not represented as a specified flux, so it is unclear that the flux out of the borehole is equal to the flux into the Culebra for each set of realizations (or even for the mean of all realizations). The PA models should compute mass balances and budgets, to demonstrate that the two boundary conditions are indeed equivalent. Specifically, the total mass of fluid and solute that the borehole model computes to enter the Culebra over 10,000 years should equal the total mass of fluid and solute that is added to the Culebra over 10,000 years in the Culebra model. Is such documentation available? It appears possible that representing the HI borehole solute flux as an initial condition in the transport equation without an accompanying fluid flux could lead to a consistent underestimate of the solute spreading away from the finite-difference cell where the HI borehole is assumed to be located.

Other Concerns about Parameters and Processes: The NAS WIPP Committee report (NRC, 1996) included a number of criticisms of the conceptual models and numerical models of the Culebra, many of which remain unresolved. Please review Chapter 6 and Appendix F of that report for more details. The most critical issues relate to the use of homogeneous and uniform Kds in each realization, and whether the very simple retardation factor concept adequately represents all of the complex reaction chemistry. This has certainly not been adequately demonstrated at the field scale. A related important issue is the accuracy of the definition of matrix diffusion processes and parameters. Another concern is the reliability of the regional

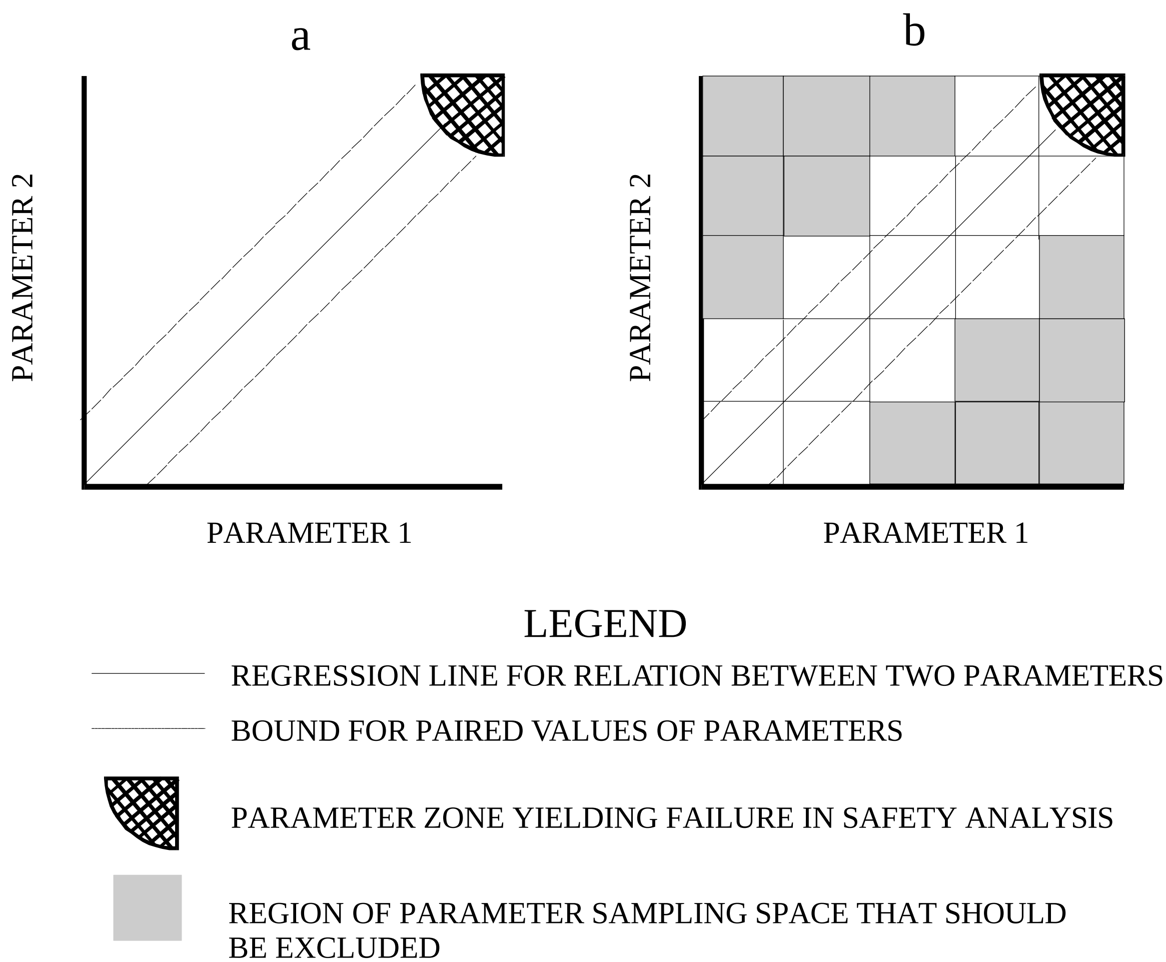

Fig. 23. Example to illustrate effect on calculated risk of independent sampling values of two parameters that are strongly correlated. (a) All data points fall within indicated bounds. (b) Independent sampling can yield paired values that are "out of bounds" and should be excluded from the PA.

transmissivity estimates for the Culebra, which were determined using inverse methods that assumed a non-leaky two-dimensional aquifer. More recent three-dimensional analyses by Sandia clearly indicated that there is significant leakage into the Culebra. A AClimate Index@ has been used as a multiplication factor in the CCA to enhance the magnitude of flow of the Culebra flow field to compensate for the lack of consideration of the additional flux through the system. However, we have not seen any rigorous analysis and documentation of the consequences of such errors, or the sufficiency of corrections applied.

An important overriding consideration is that if the volume of fluid entering the Culebra from HI boreholes is negligible or if the concentration of radionuclides in that fluid is extremely low, then weaknesses and flaws in the Culebra models become a moot point. The reliability of these calculations of fluid and solute fluxes hinges on a number of other assumptions and conceptual models about the high-pressure brine reservoirs underlying WIPP, about the pore-volume and saturation of the sealed repository, about anhydrite marker beds, about solubilities, and about a number of other issues. Some of these assumptions have changed markedly between the time of the 1992 PA and the 1996 CCA. The NAS WIPP Committee (NRC, 1996) examined the assumptions underlying the 1992 performance assessment in moderate detail. Many of the revised assumptions that were made for the CCA models were not subject to rigorous scientific scrutiny by the Committee. Where some of the CCA assumptions were examined and weaknesses in the models detected, it was too late to document the concerns in the 1996 published report of the Committee.

2.9.3 Chemical Retardation

The EEG has submitted the following four documents to the EPA on this issue:

- Copy of November 14, 1996, letter from R.H. Neill to J. Salisbury, with attachments;
- February 7, 1997, letter from R.H. Neill to F. Marcinowski, with attachment “Chemical Retardation”;
- Copy of May 23, 1997, letter from R.H. Neill to J. Salisbury, with attachments; and,

- Copy of August 29, 1997, letter from R.H. Neill to G.E. Dials, with attachments.

The August 29, 1997, letter and the attachments (EPA WIPP Docket # II-D-117) contained the EEG position on this issue based on the July 30, 1997, meeting in Albuquerque, which was organized by the EEG. Copies of this letter with the attachments were mailed to several EPA officials and the EPA WIPP docket. The DOE also sent a copy of their impressions of the July 30 meeting (Dials to Neill 8/25/97 letter with attachments, docket # II-D-115) to the EPA on August 25, 1997, four days before the EEG letter.

The EPA draft rule discusses this issue in the Technical Support Document, "Assessment of K_ds Used in the CCA", docket # III-B-4. This document makes extensive references to the DOE's August 25, 1997, letter, but no mention of the EEG's August 29, 1997, letter. Because the issue was raised by the EEG, and the July 30, 1997, meeting was organized by the EEG, it is difficult to understand why the EPA's analysis makes no mention of the EEG's summary of the July 30 meeting and the recommendations.

As described in the EEG's August 29, 1997, letter, the EEG has recommended conducting both batch and column tests for at least the actinides Pu(III), Pu(IV), and Am(III) in the Culebra brine; setting the lower end of K_d for U(VI) to be zero; conducting sensitivity analysis for potential impact of organic ligands; extending performance assessment calculations beyond 10,000 years to see how long the chemical retardation delays the releases to the environment; investigating the potential impact of nonlinear sorption on radionuclide transport; and, checking the validity of the K_d values derived from the column tests by examining the cores to identify whether the Pu and Am are present in adsorbed or crystalline solid phase.

Before discussing the specific issues and our recommendations, we wish to clarify our philosophy regarding what K_d numbers are needed for showing compliance with the numerical Containment Requirements (40 CFR 191.13) of the EPA Standards. Independent check of the CCA calculations by the EPA and the EEG show that only 3 ml/g value for K_d is sufficient for showing compliance with 40 CFR 191.13. However, that conclusion is based on keeping all the other parameters and assumptions in the CCA unchanged. It is difficult to accept a particular value or a range of values for any of the input parameters, or to accept conceptual models, on the basis of partial sensitivity analyses. We have communicated this view to the Environmental Protection Agency (EPA) in our comments on the CCA dated February 7, 1997 (Appendix 8.1) and March 14, 1997 (Appendix 8.2). The EEG position is that the values of all input parameters and the validity of all conceptual models be independently verifiable to be robust. The comments below should therefore be read with this philosophy in mind. Letter reports on this question from the EEG consultants, Dr. Don Langmuir, Dr. Leslie Smith, and Dr. Mark Brusseau, are enclosed in Appendix 8.6 of this report.

Transferability of Laboratory K_d Data to Field: Dr. Jim Davis of the U.S. Geological Survey, who attended the July 30, 1997, meeting as a nominee of the NAS WIPP Committee, raised a number of important questions concerning the applicability of the laboratory K_d data for the field conditions. This issue has been debated for many years. The latest report of the National Academy of Sciences WIPP Committee (NRC, 1996), in discussing the chemical retardation issue, states: "...there is often little basis for extrapolation of theory and lab tests to the field environment for predictive purposes". The EEG has, however, accepted the validity of the approach of using the laboratory determined values to get an estimate of the values to be used for modeling contaminant transport in the field, because, as described by Dr. John Bredehoeft at the meeting, groundwater diffusion into the rock matrix will provide opportunities for chemical retardation to occur. But this does not mean that a one-to-one correspondence may be assumed between the laboratory and field values. Dr. Brusseau has recommended additional analyses of the column experiments to help address whether the K_d values obtained under static batch conditions provide an accurate measure for dynamic field conditions. Both Dr. John Bredehoeft and Dr. Leslie Smith emphasized that the K_d range determined from batch tests applies only to the matrix porosity, and not to retardation in the fracture system with advective porosity. This is consistent with the model used in the CCA. There is no discussion of this specific issue in the DOE's August 25, 1997 letter or its attachments, extensively quoted in the EPA's Technical Support Document (U.S. EPA, 1997j).

Limited K_d Data Base: The experimental data base for the K_d values used in the CCA remains insufficient. In the absence of measured K_d values for Plutonium at oxidation states III and IV, and inconclusive results for Am^{III}, the K_d values for these three most important actinides in the WIPP inventory have had to be estimated. These estimations are based on two questionable assumptions. The first is that K_d values for actinide cations of the same charge should roughly be the same. According to Dr. Langmuir, the weakness of this assumption lies in not considering the effect of the speciation behavior of the cations on their adsorption properties. The second assumption is that predictable trends exist for the K_d values of actinide cations of different charge. The DOE used this assumption to argue that Pu^V data can be used for Am^{III}. Dr. Langmuir has shown in his letter report to EEG (Appendix 8.6) that this assumption is based on questionable data and interpretations of the experiments conducted with dilute groundwater from the Yucca Mountain site, even though, fortuitously, the same trend has been reported by some other experimenters. Results of the intact core column tests are probably of questionable value as well, because the Am and Pu input concentrations to the cores were so close to saturation with solids that precipitation rather than adsorption may have occurred.

The net result of these assumptions is the use of unjustified K_d values for the three most dominant radionuclides in the WIPP inventory. Pu^V data has been used for Pu^{III} through a two step process, both of which are questionable; first, through the predictable trend argument, for Am^{III}, and then, through the oxidation state analogy, for Pu^{III}. Similarly, Th^{IV} data has been used for Pu^{IV}, using the oxidation state analogy. Here too, besides the problems with the oxidation state analogy, there is an additional problem of an inapplicable brine (from ERDA-6 brine reservoir) having been used for the Th^{IV} experiments. As Dr. Clemo showed at the July 30 meeting, the mean K_ds measured in the ERDA-6 brine are greater than the values determined using the other three brines. Thus, the use of Th^{IV} data for Pu^{IV} also has two problems. The EEG has never understood why real data for at least the most dominant components of the WIPP waste has not been obtained. The attachment to the DOE's August 25, 1997, letter (Docket II-D-115, cited in U.S. EPA, 1997j) repeats the previously presented arguments in favor of accepting the data on other actinides at other oxidation states as surrogates for actual data on Pu^{III}, Pu^{IV}, and Am^{III}.

EEG recommends conducting both batch and column tests for at least Pu^{III}, Pu^{IV}, and Am^{III} in the Culebra brine if any credit for retardation of these actinides is to be taken in the WIPP performance assessment.

Uniform Distribution Assumption: Based on the recommendation of our consultants, the EEG now accepts the use of uniform probability distribution to represent the uncertainty in the K_d values for the CCA calculations because the experiments were not designed to provide distribution information. However, Dr. Leslie Smith has taken issue (see page 2 of his letter report, Appendix 8.6) with the CCA values for the lower and upper bounds of the probability distribution, and how these bounds are defined relative to the type of brine used in the batch experiments. The ranges for K_d relative to brine type were selected based on the average value of the sample distribution. For example, the range for Pu^{V} (and by extrapolation, for Pu^{III} and Am^{III}) used in the CCA calculations is 20-500 ml/g, which reflects values from the batch tests using deep brines, while the results with the Culebra brine had a lower range of 9.8, and therefore the assumed range for Pu^{V} should have been 9.8 to 500 ml/g. Dr. Langmuir has asked (see Appendix 8.6) why the lower range of 1-200 ml/g determined for Np^{V} was not used for Am^{III} and Pu^{III} .

Dr. Leslie Smith (in his letter report in Appendix 8.6) has also raised questions about the U^{VI} K_d data. If the negative values are ignored, the low end of the sampling range for U^{VI} is 0.03 ml/g. The zero values assigned to the negative values for the batch tests with the Culebra brine did not get passed into the CCA calculation because of a lower average value of K_d for the batch tests using deep brines. The EEG recommends that the lower end for U^{VI} K_d value be set at zero.

Non-Culebra Dolomite: The issue of the use of Norwegian dolomite K_d data, not a major concern to begin with, may be considered to be resolved because the results of these tests make their way into the final sampling distribution only once, in determining the upper bound for U^{VI} at high pH conditions.

Organic Ligands: The EEG makes the following recommendation, as suggested by Dr. Mark Brusseau (see his letter report in Appendix 8.6):

> The DOE should conduct and publish a formal sensitivity analysis to examine the potential impact of organic ligands on the aqueous concentrations of the radionuclides. The concentrations of the ligand should be varied by several orders of magnitude, and the full list of ligands provided by EEG should be used.

Additional Issues: Dr. Langmuir has questioned the results of the core column tests because of the high concentrations of Pu^{V} and Am^{III} in intake solutions possibly resulting in their precipitation as solids rather than adsorbed in the columns. If precipitation did occur, the concentrations in the rock cannot be used to define K_d values. In order to prove or disprove this concern, it is recommended that the core materials that have been drilled out be examined to identify whether the Pu and Am are present in adsorbed or crystalline solid phase.

Dr. Langmuir has also suggested that it is possible to obtain K_d values for the important actinides in a short period of time from accelerated intact core experiments performed in an ultracentrifuge. Because of the time constraints, the DOE should examine this option.

Dr. Brusseau has recommended investigating the potential impact of nonlinear sorption on radionuclide transport. This could be accomplished by calculating effective K_d values for pertinent C_0 values, using the nonlinear isotherm data available. These values should then be compared to the existing K_d range.

During discussions with our consultants after the July 30 meeting, it was pointed out that if the calculations for release were continued beyond the 10,000 year period, release to the accessible environment will be seen. Rucker (1998) also shows that a significant fraction of actinide mass will cross the LWB beyond the 10,000 regulatory time frame. Figure 24 (reproduced from Rucker, 1998) shows the fractional discharge of Uranium with a retardation coefficient of 2.0

crossing the LWB. The figure demonstrates that very little mass that enters the Culebra crosses the LWB during the initial 10,000 years and almost the entire nuclide mass fraction will cross the LWB by 70,000 years post intrusion. The EEG recommends that the performance assessment calculations be extended beyond 10,000 years to determine long-term system performance.

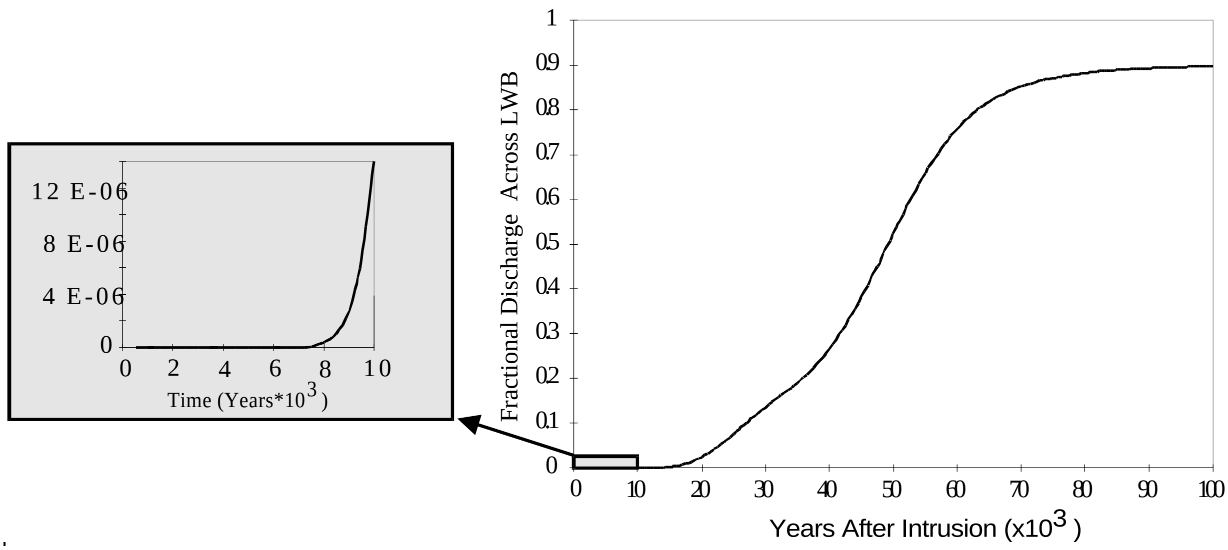

Fig. 24. Fractional Discharge Of Uranium Across The LWB Within 100,000 Years, With Blowout Section Of 10,000 Years. Reproduced from Rucker (1998).

2.10 THREE DIMENSIONAL PROCESSES AND BOUNDARY CONDITIONS

This issue was presented to the EPA staff on December 10, 1997, as "2D/3D Modeling in BRAGFLO". The EEG first brought this issue to the EPA's attention as an attachment titled "Brine Inflow From Salado: 2-D versus 3-D Geometry in BRAGFLO" to the March 14, 1997 Neill to Marcinowski (Neill, 1997b) letter. The DOE submitted a response as an attachment to the June 27, 1997 letter from G.E. Dials to L. Weinstock. The Draft Rule includes this issue as Issue F in CARD #23. The EEG position is summarized by the EPA as Comment #553 on page 115 of CARD #23, and the EPA response is provided on page 116. EEG's detailed response to the DOE and the EPA positions is provided as Enclosure 2 to this letter. DOE once again responded to this issue in attachment 6 of a letter from G. Dials to M. Kruger dated January 26, 1998. On February 17, 1998, EEG met with DOE to discuss this as well as other issues. As an outcome of this meeting, it was agreed that a single 3-D simulation be performed using the parameter values of one vector in the CCA calculations to assess the potential for impact on the CCA release calculations. A summary of the issue, the EEG's response, and the EEG recommendation to resolve the issue, follow.

The results of FEP S-1 screening analysis suggest that the two dimensional BRAGFLO model used in the CCA calculations may be misrepresenting repository performance at pressures above the anhydrite fracture pressure. There is the potential of substantially greater brine saturation in the repository at higher pressures than calculated for the CCA. The discrepancy between the 2D and 3D versions of BRAGFLO may have resulted in an underestimate of radionuclide releases to the surface.

To resolve this issue, the EEG recommended that several 3D BRAGFLO simulations of the repository should be performed using the parameter values of vectors used in the CCA performance assessment. The 3D BRAGFLO simulations should be used to provide repository conditions for the normal suite of direct brine release calculations. The calculations should also be assessed in terms of impact on spallings calculations. Spallings simulations are probably not required to assess the impact. The following criteria may be used to select the CCA vectors for running the 3D simulations to bound the magnitude of the problem:

- Since the discrepancy occurs above the fracture initiation pressure, the simulations should be limited to parameter vectors that result in pressures above 12.7 MPa at some time during the 10,000 year time frame.

- Direct brine release calculations should be sensitive to increased brine saturations above the waste residual brine saturation. Vectors that had either large brine saturations or a mobile brine component (saturations above the residual saturation) are more likely to be sensitive to increased brine inflow. Figure 5.1.5 of the preliminary sensitivity analysis report (Helton, 1996) indicates one vector with a 10,000 year pressure above 14 MPa and a brine saturation above 0.4. This is a likely candidate.

- The potential for brine consumption by corrosion should be assessed. Vectors with both slow and fast corrosion rates that also meet the above two criteria should be run.

- If the first simulations indicate a large change in saturation, then assess whether the 3D BRAGFLO simulations indicate a much larger number of significant direct brine releases than those calculated in the CCA. Simulations using brine saturations on the order of 0.1 and 0.3 should be performed.

In response to these recommendations, DOE indicated that the conditions used in the FEP S-1 investigation were not representative of CCA conditions and that increased brine inflow should not be expected for CCA conditions. If brine inflow did occur as a consequence of anhydrite fracturing, it was expected that the additional brine would be consumed through metal corrosion and therefor not increase repository saturation. At the February 17, 1998, meeting it was agreed that there was sufficient reason to further investigate the potential for greater brine inflow to the repository using 3D modeling than the calculated in the 2D model of the CCA. It was agreed that a simulation corresponding to a parameter vector that led to high pressure and anhydrite fracturing in the CCA calculations will be sufficient to demonstrate the potential increased brine inflow in comparison to the CCA calculation.

2.11 BRINE RESERVOIR PARAMETERS

The EEG raised a number of issues related to the Castile Formation brine reservoirs (Neill, 1997a, 1997b) attachments "Brine Reservoir Assumptions", Appendices 8.1 and 8.2 of this report) in commenting on the CCA. The EPA has accepted all of the EEG suggestions except the one related to the assumption of the probability of encounter of brine reservoirs, and we disagree with the EPA on this issue. The CCA assumed 8% probability on the basis of faulty assumptions. The EEG recommended 100% probability on the basis that the WIPP-12 brine reservoir was large enough to most likely extend under the repository, a conclusion also confirmed by geophysical testing directly above the repository. The EPA has sampled on a range of 1 to 60%, but has provided no basis for assuming less than 60%. Based on the arguments that the geophysical (Time-domain electro-magnetic survey) data may be interpreted to indicate the brine to be under 60% of the repository, and that some boreholes adjacent to the brine producing boreholes are known to be dry, the EEG is willing to accept the assumption of a fixed 60% probability of encounter, and recommends that a new performance assessment calculation be run with this fixed value.

According to EPA, changing the assumed brine volume of a Castile brine reservoir from 160,000 cubic meters (in the CCA) to 17 million cubic meters (in the PAVT calculation) had a noticeable effect on releases, but the compliance with the standards was still met. However, "EPA believes that the PAVT verifies that the original CCA Castile brine reservoir parameters were adequate for use in PA and comparison against the radioactive waste containment requirements." (U.S. EPA, 1997c, p. 58800). The EEG strongly rejects this argument because there are many other parameter values and conceptual and numerical models that should be changed, unless acceptable justification can be provided for the assumptions in the CCA and the proposed rule; and these changes will change the outcome of calculations. To declare an assumed value that is not otherwise justified "adequate" on the basis of limited changes in other values is, at the least, premature. 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.

2.12 WASTE ISSUES

EEG has two waste issues. One concerns assumptions of random emplacement of radionuclides in the repository and the effect this may have on the final CCDF. The other refers to the determination of quantities of cellulosics, rubber, and plastics in the waste and the control of this waste limit in the repository. These two issues will be addressed separately.

2.12.1 Assumption of random emplacement of radionuclides in repository

The assumption by DOE assumes that the waste inventory will be emplaced in the repository in a purely random manner leads to three further assumptions in the PA:

(1) The 569 CH-TRU waste streams can be sampled randomly to determine the concentrations of radionuclides brought to the surface by cuttings and cavings;

(2) the concentration of radionuclides in the area of the waste room affected by spallings releases can be assumed to be the average of the entire WIPP inventory;

(3) the concentration of dissolved radionuclides in solution in a waste panel that has a Direct Brine Release is also calculated from the average of the entire WIPP inventory.

2.12.1.1 Previous EEG comments

EEG commented on this issue in our March 14, 1997, letter to EPA. The following additional comments are similar to those of 3/14/97, and lead to similar conclusions.

2.12.1.2 EPA response to issue

EPA did not accept DOE's contention in the CCA that emplacement of waste in the repository would be purely random and that a waste loading plan was unnecessary. The EPA requested in a March 19, 1997, letter that DOE provide additional information on the possible effects of non-random loading on cuttings and cavings, direct brine release, and spallings releases. Upon review of DOE's response (Docket A-93-02 Item II-I-28 Enclosure 1, p. 8-18) "EPA determined that DOE was therefore not required to describe how the planned distribution of radioactive waste (as assumed in the PAs) would be achieved because the random distribution of waste containers in the WIPP resulted in compliance" (i.e., it did not matter to compliance how the drums were placed in the WIPP).

2.12.1.3 EEG evaluation

EEG agrees with EPA's request of DOE for analyses involving non-random loading. However, we have disagreements with several of the DOE assumptions and evaluations as well as the conclusions that were drawn from their results.

Effects on Brine Concentration. The DOE assumes that all brine in a repository would have to travel long distance through large volumes of waste to reach the point of an intruding borehole and concludes that brine concentrations of radionuclides are appropriately determined from the entire repository average.

EEG believes that while the DOE model is possible, it is not the only (and probably not the best) explanation. It certainly is non-conservative. The brine present in an undisturbed waste panel could come, more or less evenly, from all the walls, ceilings, and floors in the panel. If this occurs brine would stay close to the point where it enters the waste room or panel drift. There would be some movement down dip and this would cause water depths at maximum down dip location to be about 25% higher than the average depth (assuming 50% brine saturation). A waste room at 50% brine saturation would contain 270 m^3 of brine. The maximum brine release in PAVT is 100 m^3 and the 90^{th} percentile release is only 15 m^3. It seems unreasonable to assume that most water flowing into the intruding borehole would come from great distances. EEG believes it most reasonable to assume an average concentration of wastes from no larger a volume than one repository room. We have not attempted to estimate how much the concentration in a room would increase the CCDF. However, we note that the plutonium concentration in solution from SRS heat source waste would be at least 6 times the average at 350 years. Also, the RFETS residues are almost 15 times as concentrated in

^{241}Am as is the repository average. Americium-241 has a specific activity that is 56 times that of ^{239}Pu and it will be the dominant radionuclide in solution (in curies) for thousands of years when using either PAVT or CCA median solubilities.

EEG concludes that the amounts of radioactivity in solution from non-random emplacement could be somewhat larger than DOE has calculated and that this issue has not been adequately addressed.

Effect on Cuttings Releases. DOE had previously evaluated effects of non-random loading on cuttings and cavings releases in 1996 when responding to a Peer Review Panel concern. They ran a replicate of 100 realizations of the effect of assuming that all 3 drums in a stack came from the same waste stream (rather than random). The resulting CCDFs are included in DOE's May 2, 1997, response to EPA's March 19, 1997, request for more information. The non-random loading CCDF plots indicated mean values that were 26% higher at 0.1 probability and 22% higher at 0.001 probability than the mean for random loading.

Effect on Spallings Releases. DOE's evaluation of the possible effect of non-random loading on spallings releases considered the number of EPA waste units that would be brought to the surface if 4 m^3 of repository room volume of RFETS residues were brought to the surface. The RFETS residues were considered to be the highest activity waste stream containing more than 810 drum equivalents (0.001 of the total repository volume). The total release of 0.368 EPA units is well below the 10 EPA units allowed at 0.001 probability.

These are reasonable assumptions. However, the total EPA units should include the release from cuttings and cavings into these wastes (mean of 1.0 m^3 in PAVT). Also, the RFETS residues are not the worst waste streams for early intrusion times. There are 810 drum equivalents of heat source waste at SRS that would average 440 ci/m^3 at 100 years after closing and 7,100 drum equivalents that average 130 ci/m^3 at 100 years.

EEG has recommended before that the waste stream activity for spallings release should be a sampled value as it is for cuttings and cavings. An indication of the possible effect can be seen from PAVT volumes and EPA units released. The mean spallings volumes are 1.7 times the mean cuttings and cavings volume for scenario S1 and 1.2 times for scenario S2. Yet the mean CCDF release at .001 percent is 25% greater for cuttings and cavings (with waste stream samplings on random emplacement) than for spallings (assumed average activity).

Summary of EEG Conclusions and Recommendations. EEG believes that releases in brine could be somewhat larger (perhaps more than 100%) than calculated in the CCA or PAVT if non-random loading on a room-size scale was assumed. We agree that the cuttings and cavings releases will be about 25% higher if there is non-random loading on stacks of drums. Also, spallings releases are likely to be 25-50% higher with waste stream sampling on random emplacement and higher yet with sampling on non-random emplacement.

EEG disagrees with the DOE position (and EPA concurrence) that since non-random considerations do not show that these three release mechanisms would lead to non-compliance they are unimportant and can be ignored. The effect of these three mechanisms combined could increase the total mean CCDF at .001 probability by 50% or more. This is still a long way from non-compliance. However, there are other assumptions in PA models and parameter values that EEG does not believe have been shown to be non-conservative, that can also affect the final CCDF curve.

EEG recommends that releases from cuttings and cavings and spallings be determined from waste stream sampling based on non-random emplacement. Direct brine release values should be based on non-random emplacement on a scale no larger than one waste room.

2.12.2 Cellulosics, rubber, and plastics

DOE has concluded that a maximum repository limit of 2×10^7 kg of cellulosics, rubber, and plastic (CRP) is needed in order to prevent production of more CO_2 than can be controlled by the MgO backfill. EPA has concurred in this recommendation. The expected amount of CRP in the repository is 2.1 x 10^7 kg (U.S. EPA, 1997b, CARD 24-38).

2.12.2.1 Previous EEG comments

EEG commented on this issue in our December 31, 1997, letter to EPA. There were two concerns: (1) whether the quantities of CRP in the waste would be determined with the necessary accuracy in waste characterization; and (2) whether the proposed repository limits on kilograms of CRP would be adequately controlled by the proposed scheme.

2.12.2.2 EPA response to issue

EPA has never expressed a concern about waste characterization of CRP to DOE. They did inquire about the ability of DOE's WIPP Waste Information System (WWIS) to control the repository limits set by DOE. The possible need to control waste repository limits on a scale less than the full repository was not mentioned by EPA.

EPA has not responded verbally or in writing to EEG's concerns mentioned in the December 31, 1997, letter.

2.12.2.3 EEG evaluation

Waste Characterization. EEG is concerned about the ability to measure CRP with enough accuracy to ensure that the 2 x 10^7 kg limit will be met. Visual Examination (VE) is a method that is capable of good precision on those containers measured if all internal containers are emptied and their contents identified and weighed. However, internal containers are not always opened during VE. The preferred method of characterization is real time radiography (RTR) which is only semi quantitative (WMP weights are estimated by determining the void space and weight of waste in the drum which is not very accurate even if there is only one WMP in the container). EEG has not found a reference to the uncertainty in determining the weight of CRP in waste containers in either the DOE or the EPA reports. The EPA needs to point out where this uncertainty has been addressed, if it has been, or address the issue.

Waste Repository Limits. EEG has two concerns about the DOE plan to control CRP waste repository limits on the full repository rather than on a sub-unit (such as a waste panel). There are two concerns that do not appear to have been addressed:

(1) An excess of CRP in a waste panel could overload the MgO in that panel and since no interchange of brine between panels is assumed, it is questionable how much benefit would incur from excess MgO in another panel. Estimated concentrations of CRP do vary significantly between generating sites (e.g. at INEEL the average is 1.8 times the total inventory average);

(2) A management plan that allows emplacement of repository limited parameter quantities that vary significantly from the required average could result in a situation where the required limits could not be met by emplacing the remainder of the inventory. This is a potential problem because the actual content of waste containers will be known only as the individual containers are characterized and may be much different than the current estimates.

EEG believes that waste repository limits for CRP should be controlled on a per panel basis at least until the inventory is known with more certainty.

2.13 QUALITY ASSURANCE

2.13.1 General Comments

The 40 CFR 194.22 criteria for evaluation of the DOE's quality assurance (QA) program provide a clear list of items to be documented by the DOE. In reviewing the EPA's proposed rule for certification of the WIPP's compliance with 40 CFR 191 the EEG's primary concern was to find objective evidence to show that the EPA has examined the DOE's demonstration of compliance with the §194.22 criteria, either in the text of the proposed rule, or by reference to appropriate docket material. Because of a lack of such objective evidence, the EPA's proposed rule, CARD 22, and docket material referenced by CARD 22 do not demonstrate that many of the criteria have been met. The final rule should address these issues.

The July 22, 1996, Neill to Dials letter noted that the proposed QA chapter contained significant omissions and errors, including failure to adequately address many of the criteria in §194.22, and recommended that it be completely rewritten. Only incidental changes were made to the chapter before issuing the October 29, 1996, CCA. The Neill to Kruger August 11, 1997, letter (see Appendix 8.8) contains a later EEG review on the QA chapter of the CCA. Initial portions of this review were provided at a presentation to the EPA by EEG staff on January 21, 1997.

The CCA chapter on QA was neither complete nor accurate, as required by the §194.11. Had the DOE provided the information required by the §194.22 criteria, the EPA's efforts would have been simply to verify the DOE data. However, the EPA has attempted to gather data that shows compliance with §194.22, rather than reviewing the data as presented to them by the DOE. This seems contrary to the intent of the §194.22 criteria, which places the requirement on the applicant; for all but the initial and final criteria, §194.22 states (in §194.22(a)(2), (b), (c), and (d)):

> Any compliance application shall [provide or include] information which [describes or demonstrates] that [statement of criterion].

In the proposed rule, the EPA states that the documentation needed to demonstrate compliance with the criteria was too voluminous to be provided in the CCA. The CCA QA chapter did not, however, provide pointers to the documentation that would provide a demonstration of compliance, nor did it discuss all the programs and activities that should have met the §194.22 criteria.

Some of this voluminous documentation was viewed by the EPA during reviews, audits and inspections of the DOE and its operations, as allowed under §194.21 and §194.22(e). These EPA QA operations provide much of the evidence presented in the proposed rule and CARD-22 to support the argument that the criteria have been met. However, the intent of the audits and inspections as described in §194.22(e) was to verify execution of QA programs, rather than to establish that the §194.22(a)-(d) criteria had been met. The reports from these QA operations (as found in the EPA's WIPP docket) indicate that the EPA did not specifically address many of the §194.22 criteria, nor is there evidence in them that EPA has checked to make sure that the DOE's voluminous documentation contains the descriptions or demonstrations related to each specific criterion.

These EPA documents also do not show an awareness of all the DOE programs and activities that fall under the §194.22 criteria; this is likely related to the failure of the CCA's QA chapter to discuss these programs and activities, even though §194.22 clearly required a demonstration in the application that the NQA standards had been applied to these programs and activities. Since the EEG's day-to-day responsibilities make it familiar with many more of the activities at the WIPP than are a part of the EPA mission, some of the comments below relate to WIPP activities outside of Subpart B. EEG's basic assumption is that QA for any major activity described in the CCA which relates directly to the 194.22 criteria should be addressed in the documentation for the final rule.

The following sections contain a statement of the sense of the individual criteria, a brief summary of EPA's conclusions of compliance in the proposed rule, and the EEG's comments on that documentation. During the December 10, 1998, presentation, the EPA requested that the EEG include recommendations as to how to alleviate concerns raised; these are appended to the section for each criterion.

The term “NQA standards” as used in this review consist of the 1989-1990 Nuclear Quality Assurance (NQA) Standards NQA-1, NQA-2 Part 2.7, and NQA-3 versions as described in §194.22(a)(1).

2.13.2 Specific Comments

§194.22(a)(1): As soon as practicable after April 9, 1996, the DOE will adhere to a QA program that implements the requirements of the NQA standards.

EPA summary: The EPA proposed rule cites the Carlsbad Area Office (CAO) Quality Assurance Program Document (QAPD) included in the CCA as part of Appendix QAPD as addressing the NQA standards, and the flow of requirements from this QAPD to all subsidiary WIPP organizations. The EPA audited the CAO and found the NQA standards were implemented as required in the QAPD. CARD-22 adds that the QAPD is dated April 22, 1996, that the CAO has audited lower-tier programs to enforce the requirements of the QAPD in accordance with the NQA standards, and that these subsidiary organizations conduct their own audits.

EEG comments: The EEG review of the CCA QA chapter (Appendix 8.8) addresses DOE's response of this criterion on page 4.

The EEG agrees that the CAO has established an excellent QA program. The DOE provided the necessary information in the application for this criterion, and the EPA has verified that the WIPP adheres to a program that implements the NQA standards—for the 8 critical areas addressed in §194.22(a)(2).

The beginning of the discussion of §194.22 in the proposed rule interprets both parts of 194.22(a) as a single, interconnected section, so that the NQA standards of the (a)(1) criterion need only apply to the 8 critical areas listed in (a)(2). The language of the two criteria do not necessarily support this interpretation. Had this been the original intent, there would have been no need to divide into two sections; a single criterion could have been written to cover 194.22(a)(2), and (a)(1) could have been eliminated.

The CAO QAPD Revision 1 included in Appendix QAPD has a rather elegant process for separating QA activities for these 8 areas, and radioactive waste handling and packaging activities, from other WIPP-related processes. Section 1.1.2.3 of the QAPD establishes these areas as responsible for meeting “additional requirements”, which are extra to the “general requirements” required for other WIPP activities. The “general requirements” established throughout the QAPD are those related to the requirements of 10 CFR 830.120 and DOE Order 5700.6C, the DOE’s normal QA requirements; the “additional requirements” are those found in the NQA standards that are not addressed by §830.120 and 5700.6C. The NQA standards are much more prescriptive than are the normal DOE QA requirements--NQA-1 alone contains over 30 pages of requirements, as opposed to the less than two equivalent pages of requirements found in normal DOE QA standards.

The purpose and scope of the criteria, as found in §194.1, reference both the 1992 Land Withdrawal Act and 40 CFR 191. §191 Subpart A describes management of the waste (placing it in the disposal system), and the intent of §194.22(a)(1) seems to have been to implement the NQA standards for all WIPP activities during the operational phase, as well as for the disposal phase. The EPA’s Guidance For The Implementation of EPA’s Standards For Management And Storage OF Transuranic Waste (40 CFR Part 191, Subpart A) At The Waste Isolation Pilot Plant (WIPP), EPA 402-R-97-001, Section 2.3, states:

> For Implementing Subpart A at the WIPP, EPA interprets these definitions to mean that all activities at the WIPP up until the point of disposal must be considered in determining compliance. Specifically, this means that all activities in all WIPP facilities, both at above-ground locations and in the underground disposal system, are regulated under the standard.

Recommendation: If the intent of the criterion was that the CAO's QA program only meet the requirements of the NQA standards for the 8 critical areas listed in §194.22(a)(2), then the EEG agrees that the criterion has been met. However, the documentation for the final rule should include a rationale for considering only those areas described in §194.22(a)(2) as falling under the §194.22(a)(1) criterion.

The EPA should also be aware that the revision of the CAO QAPD included in the CCA was to be implemented program-wide for the WIPP by mid-August, 1996, not April 22, 1996, as is implied in CARD 22[1].

§194.22(a)(2) [General Statement]: The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for 8 critical activities.

EEG general comments: The EEG review of the CCA QA chapter (Appendix 8.8) addresses these criteria on page 5, pointing out that the DOE misinterpreted the (a)(2) criteria. In general, the portions of the chapter titled similarly to these criteria do not provide the requisite demonstration of compliance.

The 8 activities are individually addressed below. It is important to note, however, that the EPA's documentation of compliance relies heavily on EPA audits of the CAO, the Waste Isolation Division (WID; the Management and Operating Contractor responsible for conducting most on-site activities), and Sandia National Laboratories (SNL; the WIPP scientific advisory organization). The audit

[1]The QAPD Rev. 1 distribution letter from R. Dennis Brown, CAO QA Manager, to WIPP organizations dated June 13, 1996, requires that the QAPD be properly implemented within 60 days of receipt of the letter. The official sign-offs were on April 22, and the CAO office may have implemented it on that date, but all subsidiary organizations were not required to conform to its dictates until the much-later date.

reports from these EPA activities do not indicate that the specific areas required by each criterion were addressed, but rather show that the overall QA program of the organizations was audited.

The EEG does not agree that verification of the establishment and execution of an overall program provides an adequate demonstration of execution for the specific activities described §194.22(a)(2). The individual (a)(2) criteria would not have been written if establishment and execution of a general QA program was all that was intended. The EPA audits are a snapshot view of QA at these organizations in 1997, but many of the DOE programs and activities that fall under the (a)(2) criteria have been in operation for many years, and the data from these programs was freely used in the compliance application.

To demonstrate establishment and execution of the NQA standards on the programs and activities covered by each criterion, a formal assessment (audit or surveillance) of the process and the resulting records should be cited; the assessment should have been performed by qualified personnel, addressing compliance with QA documents which include the NQA requirements applicable as a part of the assessment. The assessment need not have been entirely devoted to that area, but should have addressed the specific programs and data falling under each criterion. The EPA should verify that the process was performed at a time when the NQA standards were in effect for that program, and that the assessment was conducted according to the requirements of the NQA standards.

Recommendation: If such an assessments are not currently available from the DOE then the EPA should require the DOE to perform and report such assessments. As a last resort, the EPA could assess the program as a part of its verification process (despite the EEG's reservations about using this approach). In any case, the documentation for compliance with the criteria should demonstrate that the NQA standards have been established and executed for the DOE programs that falls under each criterion.

§194.22(a)(2)(i): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for waste characterization activities and assumptions.

EPA summary: The proposed rule notes the current lack of waste characterization at the generator sites and describes how the proposed Appendix A Condition 2 will be used to ensure that these sites will have met the criteria before shipping waste to WIPP. The proposed rule shows evidence that a QA program adhering to the NQA standards have been demonstrated for waste characterization at one generator site (LANL) and for the WIPP Waste Information System (WWIS), a DOE computer system used to ensure that characterization and certification requirements have been met for each waste container before it is shipped. CARD 22 expands on this information, and adds that the CCA QA chapter states that the Transuranic Baseline Inventory Report (TWBIR) was prepared in compliance with the CAO QAPD and its preparation was audited by the CAO in 1995.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on pages 10 and 11.

There are two major components to this criterion: the waste characterization activities at generator sites, and the waste assumptions used to establish parameters for the performance assessment (PA) evaluation.

For waste characterization at generator sites, the EPA has presented adequate evidence that, for LANL and its use of the WWIS, the DOE has demonstrated the establishment and execution of a QA program meeting the NQA standards. The proposed Appendix A Condition 2 seems an adequate compromise method for applying the criterion to other generator sites--the criterion requires a demonstration in the compliance application, but it is obviously not prudent for these generator sites to allocate resources to WIPP waste characterization until there is some certainty that the WIPP will open.

The EPA, however, has apparently accepted DOE's statements concerning QA for the PA component (the TWBIR data) at face value. The TWBIR waste characterization data used in the CCA clearly were not gathered under the NQA standards[2], and "the QAPD" under which the TWBIR was prepared is not the revision that was included in the CCA. The single audit finding was insufficient documentation of the TWBIR process.

The version of the CAO QAPD in effect during the preparation of the TWBIR (and the audit) was Revision 0, which apparently has not been examined by the EPA (it's not a part of the CCA). Table 1-1 of Revision 0 lists NQA-1 as a commitment document, but NQA-2 Part 2.7 and selected parts of NQA-3 are only listed as guidance documents. TWBIR data used in the performance assessment should meet the requirements of NQA-3.

The EEG has often expressed concern over the changes in waste estimates for WIPP found in the various revisions of the TWBIR, and other documents that address the WIPP inventory. For example, the CCA Appendix TWBIR estimated 61787 m^3 of existing CH-TRU waste, yet the 1996 National Transuranic Waste Management Plan (U.S. DOE, 1996a) estimates 102,025 m^3 (Table 1-1) for the same parameter--a 40% increase in the amount of currently existing waste destined for WIPP. These two documents were published only a few months apart. Comparisons for RH-TRU and projected waste volumes show even greater variations. These drastic changes in inventory amounts likely would be reflected (to some unknown extent) in the amounts and types of waste characteristics and components used in developing the PA parameters on waste.

Recommendation: The EPA could examine the audit report of the TWBIR process to ensure that the NQA standards were applied to the gathering and processing of waste characterization

[2]The Waste Characterization Analysis Peer Review Report, DOE/WIPP-96-2012, states (p. 4-3): "Because there had been no prior requirements to gather these types of data under a formal quality assurance (QA) program consistent with NQA-1 requirements, and a very short response time was imposed, the sites compiled their inventories using the best available information." The Panel concluded that, given these constraints, the data submitted are conservative (overstates quantities) and the best that could be obtained within reasonable time and cost". The EEG notes that, for use in the PA, consistency with NQA-3 requirements would also have been necessary.

assumptions used in the PA, despite the Waste Characterization Peer Review's statement to the contrary. Alternately, the Waste Characterization Peer Review accepted TWBIR data even though the panel was aware of the data's QA deficiencies (see footnote). The EPA could consider whether the Peer Review Report can be used as a "qualification of existing data" as allowed by §194.22(b) as a method of meeting the criterion for TWBIR data used in the PA. Documentation of these activities should be included in the final rule or its supporting materials.

§194.22(a)(2)(ii): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for environmental monitoring, monitoring of performance of the disposal system and sampling and analysis activities.

EPA summary: The proposed rules states that the WID developed a WIPP Environmental Monitoring Plan (EMP), which the DOE states is consistent with applicable NQA standards. The EPA audit of the WID determined that the requisite QA program had been established and executed for environmental monitoring, and sampling and analysis activities. CARD 22 adds that EMP was reviewed by the EPA, that sampling and analysis for waste characterization activities was covered under the discussion for 194.22(a)(2)(i), and that "Monitoring of performance of the disposal system has not started, but EPA has no reason to believe that the QA program for this activity will not be similar to the QA program for existing monitoring activities" (p. 22-8; restated on p. 22-9).

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on page 12.

Section 8.1 of Appendix EMP does, indeed state the following (p. 8-1):

> Quality Assurance (QA) practices that cover monitoring activities at the WIPP are consistent with applicable elements of the 10-element [sic] format in ANSI/ASME NQA-1.

NQA-1 consists of 18 basic requirements; the “10-element format” is a usual method of referring to QA requirements found in 10 CFR 830.120, a different set of nuclear QA requirements written for the DOE Management and Operations (M & O) contractors such as the WID. This *faux pas* may indicate how little familiarity writers and reviewers of EMP Section 8, Quality Assurance, have with the NQA standards.

Section 8.1 later states that QA requirements from the EPA’s QAMS-005/80 were incorporated into the WID QAPD, and Table 8-1 is an attempt to cross-reference of NQA-1 basic requirements, and requirements from QAMS-005/80, to 10 CFR 830.120. This seems to be an attempt to demonstrate that the 30-odd pages of basic and supplementary requirements from NQA-1 are completely covered by the 2 page of requirements found in 10 CFR 830.120. Section 8.3, which contains the actual QA criteria for environmental monitoring, begins by stating (p. 8-3):

> The specific WIPP QA program elements/criteria that are applicable to the performance of the EMP are listed below by 10 CFR 830.120 criterion.

A comparison of this document to its predecessors may be indicative of the trend in WID QA for environmental monitoring. The 1994 Environmental Monitoring Plan (EMP), DOE/WIPP 94-024, lists the 18 NQA-1 basic requirements (p. 8-1), but follows the 10-element format from DOE Order 5700.6C (which is essentially identical to 10 CFR 830.120) in discussing QA for environmental monitoring. The 1988 “Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant”(OEMP), DOE/WIPP 88-025, also lists the 18 basic requirements, but also describes how the QA program addresses each of the NQA-1 requirements. The trend seems to be one of moving away from NQA-1. In 1988, WID had an environmental program which clearly attempted to address NQA-1 requirements; in 1994, the NQA-1 requirements were listed, but the DOE’s own internal QA requirements were addressed; and Appendix EMP (1996) seems to have completed the transition to the 10-element format.

CCA Appendix EMP Section 8 is clearly directed at compliance with 10 CFR 830.120, not NQA-1. The environmental monitoring program, and the materials in EMP, still may meet the requirements of NQA-1, but Appendix EMP does not provide clear evidence of such compliance.

For the monitoring of the disposal system portion of the criteria, the EPA seems to have been mislead by a DOE statement in the QA chapter of the CCA, that no monitoring of the disposal system had yet occurred. Appendix MON, Table MON-1 lists 11 parameters to be monitored to provide the data required by 40 CFR Parts 191.14(b) and 194.42 for monitoring of the disposal system. The Water Quality Sampling Program (WQSP) wells are specifically listed in Table MON-1 as "Preclosure Monitorable Parameters"; Appendix EMP Section 5.3.8, "Groundwater" states that the WQSP wells have been sampled since 1994. CCA Table 7-7 (p. 1-9) shows that the Culebra wells will also be a part of the postclosure monitored parameters as well.

The WIPP Site Environmental Report for Calendar Years 1994 (Westinghouse, 1995), 1995 (Westinghouse, 1996), and 1996 (Westinghouse, 1997) all contain data directly related to the 3 parameters for Culebra monitoring described in Table MON-1 (See CCA Appendix SER, taken from the 1995 report; Sections 7.1 and 7.2 describe the radiological and Culebra water level monitoring, and the 1996 report contains a section on the third parameter, direction of flow in the Culebra). It is also worth noting that elsewhere in Appendix MON (Section 3.3) the WQSP wells are described as RCRA (40 CFR 264) post-closure monitoring wells, in terms that suggest that they will be continuously monitored until at least 30 years after repository closure.

There are also 4 geomechanical characteristics listed in Table MON-1; CCA Section 7.2.2.4.1 indicates that data is currently being gathered for these, though it is apparently not yet analyzed in terms of preclosure monitoring. Geotechnical Analysis Report for July 1995 - June 1996 (U.S. DOE, 1997b), indicates that measurements of these characteristics have been made for years. Others of the 11 parameters may also have been monitored before the publication of the CCA--CCA Appendices DMP describes the program for monitoring of drilling practices (one of the 11), and DEL describes the state of drilling in the WIPP vicinity at the time the CCA was published.

The CCA QA chapter does not reference CCA Appendices GWMP and GTWP. Appendix GTMP, section 2.0, clearly demonstrates that the NQA-1 standards were established by the 1994 Geotechnical Monitoring Plan; Appendix GWMP (no date given in the CCA), section 4.0, does the same for groundwater monitoring. These documents step through the 18 NQA-1 basic requirements, explaining how the applicable ones are to be implemented. These are clear evidence of establishment of a QA program that meets the requirements of NQA-1, but are not evidence of execution of the program.

For the final part of this criterion, the EPA has misapplied the "sampling and analysis activities" to the waste characterization processes at generating sites. It would seem more logical to assume that sampling and analysis related to the environmental monitoring and monitoring of the disposal system was the intended target, as the phrase was included in the criterion for these activities, not the criterion for waste characterization activities and assumptions.

CCA Appendix AUD does contain a list of WID internal audits, and these may provide a demonstration of establishment and execution of the NQA standards for these areas. Audit I96-03 would seem to cover the WQSP wells and other groundwater monitoring programs; I94-020 covers the 1993 Geotechnical Analysis Report, and could possibly show that the NQA standards had been applied for that year. Several others (I93-03, I93-05, I93-08, I93-048, I93-056) occurred in 1993, before the WID's QA program is said by the DOE to meet the NQA standards, but a case-by-case review may show that at least some of these can be used. The CAO's QA department may also have performed assessments specific to environmental monitoring that considered compliance with the NQA standards.

Recommendations: NQA-1 requires periodic assessment of programs by QA organizations, and the WID Environmental Monitoring Program has been in operation since 1985. The CAO, or the WID, QA departments should have assessed the program by now to ensure that NQA-1 requirements had been properly addressed in the program (that the program is adequate), and that the documentation from the program meets these requirements (that it has been effectively implemented).

The EPA should review reports from these assessments and cite them in the documentation of the final rule as a demonstration of establishment and execution of the NQA standards for environmental monitoring.

The CAO or the WID should also have assessed the WQSP (or the entire Groundwater Monitoring Program), and the Geotechnical Analysis Program. The EPA should review these reports, and cite them as a part of the demonstration of establishment and execution of the NQA standards for this criterion.

Sampling is an integral part of these programs, as are some analysis activities. However, the WQSP samples have been sent to contract laboratories for analysis, and radionuclide determinations from the Environmental Monitoring Program samples have also been performed by contract labs. The EPA should verify that contracts for these analyses include the proper QA requirements.

§194.22(a)(2)(iii): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for field measurements of geologic factors, ground water, meteorologic and topographic characteristics.

EPA summary: EPA's proposed rules states that the EPA audit found the QAPD and WID QA program complies with the NQA standards. CARD-22 indicates that QA of current WID measurements related to subsidence and disposal room monitoring were the field measurements of geologic factors that were considered; that "Groundwater monitoring activities previously conducted at the site also adhere to WID QA documents"' and that the DOE has demonstrated to the EPA that meteorologic information from pp. 2-178 to 2-180 in the PA came from geological data and information rather than from meteorological field measurements. The data generated from topographic characterization were evaluated under the qualification of existing data (QED) process allowed by §194.22(b).

EEG comments: The EEG review of the CCA's QA (Appendix 8.8) chapter addresses elements of this criterion on pages 12 through 15.

Geological factors. EPA was apparently mislead by the CCA QA chapter, which only discussed subsidence and disposal room monitoring in the section that addressed this criterion, citing WID documents. Credit for the current WID QA program does not cover the data from WID's disposal room monitoring program used in the performance assessment, for which MONPAR Sections 3.1 and 3.2 indicates data from pre-1991 was used for disposal room monitoring, and pre-1994 for subsidence.

More importantly, however, SNL was responsible for much of the work related to field measurement of geologic factors used in the CCA, particularly those geological factors used in PA. The CCA QA chapter offers a rationale for considering QA for field measurements of geological factors during site selection and characterization activities as satisfactory (see p. 5-6), but the EPA has not cited that rationale (nor should they; see EEG's review of this rationale, on p. 13 of the CCA QA chapter (Appendix 8.8) review). In addition, the parameters used in PA are based on geological field measurements--pressures at the repository level, strata thicknesses, etc.

The following description of a field measurement is an illustration of the sort of field measurement of geologic factors for which the EPA may want to be able to demonstrate the criterion has been met. The citing of "karst topography"--the possibility that dissolution of the salt beds in which the repository lies may cause a regulatory release of radionuclides--is an argument that refuses to die, despite the DOE evidence that has convinced the EEG, the NAS, and other organizations that such deep dissolution is unlikely. Testimony at recent (January 1998) EPA public hearings on the proposed rule again addressed the topic, and may become a part of lawsuits filed on the WIPP. Proof of adequate QA for measurements that defend against this argument could be an important part of such lawsuits. From CCA Appendix GCR Section 6.3.5:

> Additionally, brines in the sands of the underlying Bell Canyon Formation have been tested. These fluids are under sufficient head to allow them to reach the Salado salt. Because the brines are under saturated, they could dissolve the salt. However, to reach the Salado, these fluids would have to first penetrate the Castile Formation. Permeabilities (or lack of permeability) of the Castile and Salado Formations at the site have been determined by drill-stem tests in two exploratory holes: ERDA No. 9 and AEC No. 8. The tests, summarized by Lambert and Mercer, 1977, Tables 1 and 2, indicate that the two formations are extremely tight.

Appendix GCR, the Geological Characterization Report, contains many examples of field measurements of geologic factors. The term "field measurements" is not defined in §194; a definition that included the laboratory measurements taken from field samples would provide a list of many additional geological factors included in the CCA. Appendix GCR also contains data from these kinds of measurements, on which many of the PA parameters are based.

Groundwater**.** For the groundwater portion of this criterion, CCA Appendix SER (1995 Site Environmental Report) Chapter 7 states:

> The data obtained by the Water Quality Sampling Program (WQSP) in 1995 supported two major programs at the WIPP: Site Characterization and Performance Assessment in compliance with 40 CFR 191...Surveillance of hydrological characteristics in the Culebra provides data which can be used to detect changes in water characterization. It also provides additional data for use in hydrologic models designed to predict long term performance of the repository. Data is gathered from 64 well bores; five of which are equipped with production-inflated packers to allow groundwater level surveillance of more than one producing zone through the same well bore.

> Groundwater Quality data were gathered from ten wells completed in the Culebra member of the Rustler formation and one well completed in the Dewey Lake formation...Seven wells were drilled in the latter part of 1994 constructed for the explicit purpose of gathering water quality data. These wells are constructed with fiberglass casing and screens that will not bias sample collection. In 1995 samples were collected from old as well as new wells.

If data from these wells are used as described, then the requirements of NQA-3, which contains additional requirements for the collection of scientific and technical information to be used for site characterization, should also have been applied to them. The seven wells mention in the second paragraph quoted above are the WQSP wells[3].

CCA Appendix HYDRO contains many statements based on measurements of groundwater--transmissivities, potentiometric-surface maps, ion concentrations, etc. The "Purpose and Scope" section indicates that the USGS performed the activities that resulted in these measurements:

> This report discusses the ground-water systems and the interpretation of test results in the water-bearing zones above and below the proposed facility. Hydrologic data used in these analyses were collected during 7 years beginning in 1975 and were from 39 test holes drilled for, or converted to, hydrologic test holes. The study included: the determination of potential ground-water flow boundaries; potentiometric heads; ground-water chemistry; and hydraulic properties obtained through pumping, slug, pressure-pulse, and tracer tests.

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[3] The WQSP wells not only used special casings and screens, they were also established by air drilling, to ensure that drilling mud did not affect the water sampling process. The DOE has recently stated that it believes that only one borehole in the nine townships surrounding the WIPP used air drilling techniques; see Dials-to-Kruger letter dated January 26, 1998, p. 2.

> The hydrologic investigation is part of a comprehensive study related to site characterization and validation conducted on behalf of the U.S. Department of Energy by Sandia National Laboratories.

Other parts of the CCA contain field measurements of geological factors and groundwater, Chapter 2 in particular. For instance, Table 2-4 shows transmissivity and porosity of the various subunits of the Rustler formation; Section 2.2.1.4.1.1 lists these values for specific boreholes.

No QA for any of these sorts of measurements is described anywhere in the CCA, or in the EPA's proposed rule documentation, that the EEG has been able to identify. The QA for these measurements may have been performed under the SNL Qualification of Existing Data (QED) program (see CCA Table 5-5, p. 5-41) allowed by §194.22(b), but there is no statement in either the CCA or the EPA's proposed rule documentation pointing to QED as covering a portion of this criterion.

Meteorologic Characteristics. QA for field measurements of meteorological characteristics as required by (22(1)(2)(iii)) is not described in the CCA. The EPA asked the DOE for additional information. CARD 22 states (p. 22-11):

> Supplementary information sent by DOE on January 24, 1997 demonstrated to EPA that the measured meteorologic information in pages 2-178 thru 2-180 of the CCA was not used in the performance assessment (PA). DOE demonstrated that the PA instead used meteorological information obtained from geological data and information (Docket A-93-02, Item II-I-03).

This explanation alters greatly the information actually provided by the DOE. Item II-I-03 comments concerning meteorological data are:

> The meteorological data were included in the CCA in response to 194.14(i). The CCA does not contain information on the QA program for meteorological data because this data is not used in the PA.

The EEG also finds nothing in §194 that limits the criteria to consideration of only those data used in the PA. The data used in the CCA on pages 2-178 through 2-191 is from the WID meteorological tower data collected as a part of the WID Environmental Monitoring Program during the years 1990-1994, and there is no demonstration of adherence to a QA program that establishes and executes the requirements of the NQA standards for this data. Note that the dates for these data apparently precede the CCA QA chapter's date for adherence to the NQA standards at WID, which was established as December 1994.

Topographical Characteristics. §194.14(h) requires that the CCA include topographic maps which show contours, WIPP site boundaries, and the location of wells in the vicinity of the disposal system. These would seem to be the topographic characteristics addressed by this criterion.

It is not a demonstration of compliance to simply state that the Qualification of Existing Data (QED) process was executed on topographic characteristics, as is done in both the CCA (p. 5-6) and CARD 22 (p. 22-11, in 22.D.5); the specific instance of QED which qualified the data should be listed and discussed. DOE's QED process used Independent Review Teams (IRT) and Peer Reviews to qualify data; topographical characteristics would not seem to be a part of any of the data packages qualified by IRTs as listed in CCA Table 5-5, nor do the discussions of peer review in the CCA (Chapter 9 and Appendix PEER) mention topographical characteristics. The EEG also could not locate discussions of topographical characteristics in the reports of the peer review panels conducted in 1996 and 1997.

The §194.14(h) requirement for a topographic map that shows the locations of wells in the vicinity of the WIPP seems to have been covered by CCA Appendix DEL, Figure DEL-6[4]. This data was probably gathered as a part of the WID effort to monitor changes in WIPP-area drilling practices, as outlined in CCA Appendix DMP. The legend on this map indicates that locations of well sites were updated after the WID had within 1 mile of the WIPP boundary was updated to 08/06/96--a date well after the WID is said to have a QA program that adheres to the NQA requirements. This portion of the §194.14(h) requirement is likely the most important

Recommendation: The EPA should review the CCA for field measurements of the four areas cited in this criterion to ascertain if the QA processes utilized by the DOE for these field measurements meet the criterion. Measurements of geologic factors and groundwater used in support of the PA were the targets of the IRT reviews listed in Table 5-5 of the CCA. The EPA should correct the support documentation in the final rule to reflect that QA for field measurements of geologic factors and groundwater measurements is covered by §194(b), and cite data for specific parameters examined during the EPA's Audit of the Parameter Traceability and Qualification of Existing Data (II-A-48) as verification of the QED for this criterion. For meteorological and topographical characteristics, the EPA should require that the DOE demonstrate that the measurements presented in the CCA was gathered under QA program that established and executed the NQA standards, or present traceable evidence that these measurements were processed under §194.22(b). Reference to these statements should be a part of the EPA's documentation for the final rule.

§194.22(a)(2)(iv): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for computations, computer codes, models, and methods to demonstrate compliance with the disposal regulations in accordance with the provisions of this part.

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[4]Figure DEL-6 is not a topographic map as §194.14(h) specifies, but it does show the locations of the types of wells specified in the criterion.

EPA Summary: The proposed rules states that the requirements of the NQA standards for computations and computer codes are in the DOE QA program, in Section 6 of the CAO QAPD and also in SNL and WID QA documents. Review of the CCA (Section 5.3.20 is included verbatim), and audits of SNL and WID show that the NQA standards have been implemented. CARD-22 also cites a review of procedures and previous assessments (apparently DOE assessments) as evidence that show the requirements have been met, and states that QA for generator sites computer codes were addressed in the waste characterization section.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on pages 15 through 18.

Neither the proposed rule nor CARD 22 address models and methods to demonstrate compliance, and computations (which are not always computer codes) is only lightly touched on. The WID keeps track of huge amounts of information related to other §194 criteria (meteorological data, environmental monitoring data, geotechnical monitoring data, WIPP area drilling activity data, etc.); these data are likely kept in databases, but there is no mention of QA for these areas either in the CCA or in the documentation for the purposed rule.

The meaning of "methods to demonstrate compliance" is not clear, but if the QA chapter of the CCA was a method to demonstrate compliance with the disposal regulations then the adequacy of any QA activities applied must be considered to have failed to meet the criterion.

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Recommendation: The EPA documentation should be more specific in its descriptions of EPA auditing activities for software. A demonstration of execution (an assessment) of the NQA standards for NDA at LANL, the WWIS, and the WID database system(s) should be cited in the documentation for this criterion. The documentation should also reference the DOE's audits the PA process, and of the PA software, as demonstrations of execution of the NQA standards for these computer codes and models.

The EPA will rely on future auditing/inspection activities at generator sites to establish that this criterion is met before these sites ship waste to WIPP; a qualified NQA software auditor should therefore be a part of these audits.

§194.22(a)(2)(v): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for procedures for implementation of expert judgment elicitation used to support applications for certification or re-certification of compliance.

EPA summary: The proposed rule cites CAO's Team Procedure 10.6 and the CTAC Desktop Instruction 1, used for the waste particle size expert judgment elicitation (the only one that has occurred), and cites the discussion of the proposed rule for §194.26. CARD 22 states that the CCA that the CAO QAPD provides for adequate control of any future expert judgments that the DOE may conduct, that he expert judgment of waste particle sizes process was observed and audited by the EPA, and was conducted in compliance with the criterion. CARD-22 references CARD-26; both the proposed rule for §194.26 and CARD 26 discuss QA for the waste particle size expert judgment elicitation in fulsome detail.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on page 18, in a brief paragraph which points out other WIPP activities that might be considered as expert judgment elicitations.

The EPA has presented a demonstration of establishment and execution of the NQA standards for the waste particle size expert elicitation in the documentation for the proposed rule, though it could have been focused more on addressing the §194.22(a)(2)(v) criterion.

However, other panels convened by the DOE would seem to fall under the requirements of this criterion. CCA Appendix PEER_PIC contains the peer review report on passive institutional controls

(PICs); it contains the following statements concerning expert judgment in section 4.1.4, titled "Expert Judgment and Peer Review":

> The use of expert judgment, either by an individual expert or a panel of experts, is permissible under 40 CFR Part 194.26(a) to support the information in the CCA if that information cannot reasonably be obtained through data collection or experimentation...The conceptual design principles presented in the Conceptual Design Report seem to rely heavily on the results of the expert judgment process described in Trauth *et al.* (1992)... The PTF and preparers of the Conceptual Design Report have somewhat blurred the line between reliance on expert judgment and the peer review process by incorporating both processes; their approach is certainly not precluded by the regulations.

Trauth, *et al*. (1993) is "Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant". The peer review panel, with full knowledge of the requirements of §194.26, obviously concluded that the Trauth, *et al*. report was generated by an expert judgment elicitation group. The discussion preliminary to the §194 criteria would seem to have addressed the Trauth, *et al.* document straight on (61 FR 5228):

> Typically, expert judgment is used to elicit two types of information: (1) Numerical values for parameters (variables) which are measurable only by experiments that cannot be conducted due to limitations of time, money and physical situation; and (2) essentially unknowable information, such as which features should be incorporated into passive institutional controls that will deter human intrusion into the repository.

CCA Appendix EPIC consists of "Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments, June 4, 1996". The second paragraph of this report states

> A task force was formed to estimate the credit for the passive controls for the WIPP repository. The estimate was constrained by the use of existing conceptual designs of these controls, the use of historical analogues for the endurance of materials and structures, the consideration of possible failure modes for each control, and the regulatory assumption of societal "common denominators."

This also seems to be a collection of experts gathered to use their various expertises for determining a value that cannot be obtained by scientific means--in short, an expert judgment.

Recommendation: The EPA should consider whether the Trauth, *et al*. (1993) report is an expert judgment elicitation, and whether other expert judgment elicitations are utilized in the CCA, and analyze the QA applied to any that meet the criteria. Both reports suggested above could be considered to have met this criterion by QED as allowed through §194.22(b), as a peer review of the PICS processes is reported in CCA Appendix PEER_PIC. The final rule for this criterion should describe or reference the process the EPA uses for determining what qualifies as an expert judgment under this criterion, and describe the demonstration of establishment and execution of the NQA standards for any additional expert judgments found.

CARD 22.F.4 contains the following sentence:

> The CCA also indicates that the CAO established and executed a QA program in compliance with NQA requirements for all items and activities important to the containment of waste in the isolation system, including for procedures that may be developed for implementation of future expert judgment elicitation.

The sentence should be revised, as it is a logical impossibility; a QA program cannot be executed on procedures that have yet to be written. The sentence could easily be interpreted as an unwarranted attempt to aid the DOE’s efforts at compliance.

§194.22(a)(2)(vi): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for design of the disposal system and actions taken to ensure compliance with the design specifications.

EPA summary: The proposed rule states that the SNL QA program covered seals design, that the seals design was extensively reviewed by other organizations, and verified by a combination of NQA-1 3S-1 methods. The EPA audits show that WID and SNL programs are adequate and properly executed. CARD-22 adds that no QA deficiencies related to design considerations were noted in the EPA audits of SNL or WID, and quotes portions of of the CCA QA chapter (Section 5.1.6) concerning design of the repository.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on pages 19 through 21.

The EEG agrees that the repository seals design program was excellent. Perhaps the best demonstration of establishment and execution of design criteria for seals is not in the CCA QA chapter, or in EPA documentation for the proposed rule, but in CCA Appendix SEAL, Section 1.4, "Sealing System Design Development Process":

> The design team included specialists drawn from the staff of Sandia National Laboratories, Parsons Brinckerhoff Quade and Douglas, Inc. (contract number AG-4909), INTERA, Inc. (contract number AG-4910), and RE/SPEC Inc. (contract number AG-4911), with management by Sandia National Laboratories. The contractors developed a quality assurance program consistent with the Sandia National Laboratories Quality Assurance Program Description for the WIPP project. All three contractors received quality assurance support visits and were audited through the Sandia National Laboratories audit and assessment program. Quality assurance (QA) documentation is maintained in the Sandia National Laboratories

> WIPP Central Files. Access to project files for each contractor can be accomplished using the contract numbers specified above.

The paragraph is an example of the kind of description the EEG expected to find in the CCA for all the DOE programs that fall under the §194.22 criteria.

QA for other portions of the repository design are more problematic. The statements quoted in CARD 22 from the CCA QA chapter do not provide a demonstration of establishment and execution of the NQA standards to the repository design process--the intent of these statements seems related more to establishing that a validation process took place, rather than discussing QA for the design activities. The quoted material addresses only NQA-1 criteria, and CARD 22, Sections 22.G.3 and 22.G.5, indicates that the EPA may used only NQA-1 in consideration of this criterion. Design of the repository as described in the CCA, however, includes site characterization activities, for which NQA-3 also applies.

The criterion seems to be related to §194.14(b), which requires that the compliance application include a description of the design of the disposal system. The CCA contains discussions of repository design in Chapters 2, 3, and 6, as well as CCA Appendix DVR (the Design Validation Report). CCA Section 3.2 gives an indication of the types of information that the §194.22(a)(2)(v) criterion should be applied to:

> A preliminary design of the WIPP repository was presented in the FEIS (DOE 1980). Validation efforts for the WIPP repository preliminary design began in 1981 with the Site and Preliminary Design Validation (SPDV) program. The SPDV program was implemented to further characterize and validate the WIPP site geology and to provide preliminary validation of the underground excavation. The SPDV program involved the excavation of four full-sized disposal rooms, excavated 13 feet (4 meters) high, 33 feet (10 meters) wide, and 300 feet (91 meters) long, and separated by 100-foot (31-meter)-wide pillars. Data obtained from geologic field activities and

> geomechanical instrumentation were analyzed to determine the suitability of the design criteria and design bases and to provide confirmation of the underground opening reference design. Analyses of these preliminary designs performed by the WIPP architect and engineer are included in Appendix DVR. These analyses considered expected creep closure rates in determining disposal room sizes. Information in Appendix DVR (Section DVR.6.4.2) meets the criterion specified in 40 CFR § 194.14(b)(2).

Initial design activities for the repository took place in the 1970s and 1980s, well before any part of the WIPP project had established QA programs which met the requirements of the NQA standards. CCA Appendix DVR, for instance, was published in 1984. QA requirements during these early years were rather loose compared to those of the NQA standards; the following is from WIPP-DOE-71, "Design Criteria Revised Mission Concept - II Waste Isolation Pilot Plant", page 1-16:

> The WIPP Project Office (WPO) and the major project participants will be responsible for the establishment and implementation of adequate quality assurance programs for their respective scopes of work. These programs will be developed, using ANSI N45.2 - 1977 as a guide.
>
> Formal quality assurance programmatic requirements will not be contractually imposed on WIPP construction contractors or suppliers.

On the plus side, ANSI N45.2 -1977 was a precursor to NQA-1, but its obvious that the requirements of the NQA standards was not met by this document.

Design of the repository would also seem to include such relatively recent changes in the design of the repository as the 1996 decision to use magnesium oxide as a backfill material. Earlier design documents mandated completely filling rooms with salt backfill. The criterion seemingly requires demonstrating that the NQA standards have been established and executed for a wide range of programs over a long period of time, in which multiple changes have occurred. Establishing adequate QA for these changes would enhance confidence that all the potential effects of these changes have been taken into consideration.

Recommendation: The EPA should establish which programs and activities relate to design of the disposal system, and include a demonstration of establishment and execution of the NQA standards for these programs and activities in the documentation for the final rule. Since much of the information predates the use of the NQA standards for WIPP activities, the EPA should consider whether or not a QED process as allowed by §194.22(b) has been applied to these areas, and include that information in documentation of the final rule.

§194.22(a)(2)(vii): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for collection of data and information used to the support compliance application(s).

EPA Summary: The proposed rule states that SNL implemented numerous QA procedures to ensure the quality of data and information, and that EPA's audit of SNL found its QA program to be adequately implemented. CARD 22 notes that DOE audits have also concluded that the SNL QA program has been effectively implemented.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this criterion on pages 21 and 22.

The SNL's QA procedures do not address collection of all of the data for even the PA, SNL's foremost contribution to the compliance application. The data from the TWBIR, used to establish parameters for the PA, was not collected under a QA program adhering to the NQA standards (see EEG comments concerning waste characterization above).

The main point of EEG's CCA QA chapter review for this criterion is that all data used in support of the CCA was not collected by SNL, and cites several parts of the CCA for which SNL should not be held responsible. SNL has no procedures which specifically address collection of data and information for the DOE's compliance applications; the EPA apparently accepted the DOE statements from the CCA QA chapter at face value.

This is a "catch-all" criterion, and various descriptions of the huge amount of data and information in the CCA was cited in nearly every media article on the CCA's publication. The data and information was gathered over a 20 year period, for most of which only portions of the NQA standards were in effect. The effort should be to demonstrate that any of this data and information which is important to compliance has been collected under the NQA standards.

Recommendation: The EPA should review the CCA for data and information other than that covered by the other (a)(2) criteria which is important to compliance, and cite the review, and a demonstration of establishment and execution of the NQA standards, for any found not to be a part of the other (a)(2) criteria. The EPA should rewrite section 22.H of CARD 22, and revise the proposed rule, to remove the QA responsibility for all data in the CCA from SNL's shoulders.

§194.22(a)(2)(viii): The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for other systems, structures, components, and activities important to the containment of waste in the disposal system.

EPA Summary: The proposed rule states that neither the DOE nor the EPA have identified any activities not already covered which require QA controls, and that the EPA audits have determined that the QA organizations for WIPP have authority, access, and freedom to identify other items affecting the quality of waste isolation. CARD 22 adds nothing of substance.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements related to this criterion on page 22. EEG suggested that QA of the interface between the DOE and the BLM concerning DOE review of proposed mineral resource leases in the WIPP area could be important to waste isolation in the disposal system, referencing a WIPP docket item that pointed out problems in this area in the past.

Recommendation: While not a part of the criterion, it would useful to cite any review activities by the DOE (or the EPA) that demonstrate that this criterion has been addressed.

§194.22(b): The compliance application shall include information which demonstrates that data and information collected prior to the implementation of a QA program adhering to the NQA standards have been qualified in accordance with an alternate methodology approved by EPA, which employs peer review, corroborating data, confirmatory testing, or a QA program equivalent in effect to the NQA standards.

EPA Summary: The proposed rule cites the Independent Review Team (IRT) findings of QA programs equivalent in effect to the NQA standards listed in the CCA QA chapter (Table 5-5), the peer reviews conducted under NUREG-1297 used to qualify existing data for engineered systems, natural barriers, waste form, and disposal room data. The EPA performed two audits tracing new and existing data to their qualifying sources and found that equivalent QA programs and peer reviews were had been properly applied. EPA "concluded that existing data from peer-reviewed technical journals was appropriate since the level of such reviews was likely to provide QA equivalent to NUREG- 1297...". The EPA proposes approval of these three methods--peer review, equivalent QA program to the NQA standards, and peer-reviewed technical journals-- for qualification of existing data. CARD 22 adds that the T=0 process as well as the IRTs were used to determine equivalency of QA programs to the NQA standards, and describes the two audits as having been of SNL data used in the PA.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses this criterion on page 5.

There appears to be environmental monitoring data that was gathered before the NQA standards are said to have been established for the WID; this data is cited and used in the CCA, but it was not addressed by IRTs or the peer reviews, and does not appear to have been published in peer-reviewed technical journals. The CCA Appendix SER (U.S. DOE, 1996c, Chapter 7), states:

> Background water quality data were collected from 1985 through the 1990 sampling period as reported in DOE/WIPP 92-013, Background Water Quality Characterization Report for the Waste Isolation Pilot Plant. This background data will be compared to water quality data collected throughout the operational life of the facility. Pre-operational data gathered in the interim period will be used to strengthen the background data, to evaluate the need to make adjustments to comparison criteria...

The 1985-1990 data was collected as part of the Radiological Baseline Program, as found in CCA Appendix RBP. The RBP program measured air, surface and ground water, and soil. The Executive Summary of this Appendix states:

> This program was designed to provide preoperational measurements of radioactivity in environmental samples that will serve as a basis for evaluating similar data collected during the WIPP Operational Environmental Monitoring Program. The RBP data analyzed in this report cover the period from 1985 through 1989. Sample types included in this report are airborne particulates, soil, surface water, groundwater, sediments, and six types of biotic tissue sample.

This intended use of this data is echoed in Section 1.4. These would seem to be part of the environmental monitoring required as a part of the §194.22(a)(2)(ii) criterion. If this earlier data is to be used as indicated, then it would seem to need the provisions of §194.22(b), qualification of existing data, applied to it, as it precedes the date established by the CCA QA chapter (December, 1994; U.S. DOE, 1996c, p. 5-52) for adherence to the NQA standards at WID. Appendix RBP Section 1.4 indicates that the Waltz Mill Laboratory performed the sample analyses for this program, and these analyses would seem to fall under the §194.22(a)(2)(ii) criterion also.

There may be other data that should undergo QED cited in the CCA. Groundwater and other site characterization activities have been performed for 20 years; CCA Section 9.4.8 describes the INTRAVAL WIPP2 study used data from sixty wells and also included extensive modeling which apparently has been used in the WIPP considerations. The penultimate sentence of the section states:

> The applied stochastic models have proven to be valuable tools in assessing the effect of uncertainty due to heterogeneity on the performance of a repository.

The EPA's acceptance of existing data from peer-reviewed technical journals conflicts with the NQA standards, at least for site characterization activities. NQA-3 Supplement 3SW-1 Section 9 begins:

> Data to be used which were not collected under the control of a quality assurance program in accordance with this Standard shall be qualified for their intended use. This includes data collected from such sources as professional journals, technical reports, and symposia proceedings.

The claim that such level of review of such articles is likely to provide equivalent QA to NUREG-1297 peer review standards might also need to be reconsidered. For example, review by other DOE personnel is limited in NUREG-1297.

Recommendation: The EPA should reconsider the use of data from peer-reviewed technical journals for site characterization activities as an acceptable method under this criterion. The EPA should review the CCA for data related to the §194.22(a)(2) criteria that precede adherence to the

NQA standards, and determine if the programs cited under this criterion have assessed and qualified that data. The conduct of this review should be recorded in the documentation of the final rule.

§194.22(c): The compliance application shall provide, to the extent practicable, information which describes how all data used to support the compliance application have been assessed for their quality characteristics, including accuracy, precision, representativeness, completeness, and comparability (these characteristics are abbreviated as "the PARCC characteristics" in the discussion below).

EPA Summary: The proposed rule describes the CCA's statement that it was not practicable to document data quality characteristics (DQCs) in most cases. The DOE clarified, but did not substantially alter its approach in response to an EPA request for additional information; while the EPA agreed that the DQCs cannot be appropriately applied to parameter values the measured data on which they were based could have been assessed for them. Because the DOE misinterpreted the requirement, the EPA assessed SNL data records packages and found that for newer data, experimental plans generally addressed DQCs including the PARCC requirements, and for older data laboratory notebooks supplied some information related to DQCs. The EPA also "concluded that the peer review panels considered the use of DQCs in determining that such data were adequate", agreed with the DOE argument that collection of most data under programs equivalent to the NQA standards was adequate evidence of the quality of the data, and concurred with the DOE that uncertainty in data measurements as reflected in DQCs has a minor effect on compliance certainty compared to other PA uncertainties. CARD 22 adds that EPA performed a review of parameters discussed at length in a Technical Support Document for §194.23, and notes that the reviewers specifically looked for evidence of DOE's assessment of the PARCC characteristics. CARD 22 also offers as an example of EPA's assessment of DQCs a discussion of two parameters, for which "instrument calibration, calibration records, acceptance criteria, and procedures for calibration checks" were documented that the EPA considered to be adequate to demonstrate assessment of DQCs.

EEG comments: The EEG review of the CCA's QA chapter (Appendix 8.8) addresses elements of this topic on page 5, with a more thorough discussion on pages 32-35.

The CCA QA chapter specifically lists waste characterization and environmental data are two areas to which DQCs should be applied, but does not provide a demonstration of how they were applied in these areas for the WIPP--and the EPA proposed rule documentation doesn't, either. For the record, the EEG notes that CCA Appendix EMP, Section 7, describes how environmental monitoring addresses accuracy, precision, an comparisons, as well as other DQCs not a part of the PARCC requirements, and the TRU-Waste QAPP (U.S. DOE, 1994), Section 3.2, describes required validation methods for waste characterization which address precision, accuracy, completeness, and comparability. Appendix MON contains a probably identical discussion to that in EMP.

CCA Appendix GCR, the summary of USGS data used, indicates that accuracy and precision were considered (see sections 7.6.13 and 10.7.6, where concerns are raised due to analysis of accuracy and precision of measurements is discussed). There are other similar, rather minor discussions in many appendices, but there are certainly no indications that a systematic consideration of DQCs, "...for all data..." was a part of the WIPP project.

Both the DOE and the EPA discussions of this topic seem to miss the point of DQCs; the DOE saw them as related to the uncertainty of measurements, the EPA is willing to accept instrument calibration data as evidence that DQCs have been assessed.

DQCs relate to the intended use of the data. In an ideal world, the use to which the data is to be put is known, and the PARCC requirements are established in advance of the taking of measurements to demonstrate the limits of acceptability of the data for these uses. The WIPP studies were not developed along these lines; this criterion was not promulgated until well after most of the basic measurements for disposal considerations at the WIPP had already been taken. The lack of evidence of systematic DQC assessment at WIPP does not invalidate any data, it merely prevents taking credit for additional confidence in the supportive value of the data. The criterion does not require the DOE to assess DQCs--it only requires that the DOE show in the compliance application how they were assessed, to the extent practicable. The extent practicable for past WIPP activities was obviously near nil.

Recommendation: EPA should consider rewriting the final rule discussion related to this criterion along the lines of the EEG comments above. The EPA may also wish to consider including in the final rule a more specific criterion for the establishment of DQCs for data to be used in support of future applications.

§194.22(d): The compliance application shall provide information which demonstrates how all data are qualified for use in the demonstration of compliance.

EPA Summary: The proposed rule states that the SNL generated a table providing information of how all data in the PA were qualified; the EPA audited existing QA programs and determined that data is qualified for use in accordance with the NQA requirements. CARD 22 adds discussions of the T=0 process, QED, peer review, and the SNL QA program, noting that these were audited by the EPA.

EEG comments: The attached EEG review of the CCA's QA chapter addresses elements of this topic on page 6.

The CCA QA chapter and the EPA's proposed rule and CARD-22 contain adequate descriptions of how data used for PA parameters were qualified--but this is certainly not "all data" used for demonstration of compliance. Many of the CCA Appendices--RBP, GTMP, GWMP, USDW, to name a few--were not a part of the PA process.

Recommendation: The EPA should review the CCA to establish a list of the data for which the application should demonstrate how it was qualified, and ensure that the documentation reflects the elements of this list.

§194.22(e): The EPA will verify appropriate execution of quality assurance programs through inspections, record reviews, and record keeping requirements.

EPA summary: The proposed rule cites the EPA audits already conducted, and proposed reaudits and future waste generator site inspections. CARD 22 lists the specific audits, describes the auditing process used, and notes again that EPA did not expect all necessary QA documentation to be provided in the CCA because of its voluminous nature.

EEG comments: The EPA has met this requirement, in that it has adequately verified that, during the year 1997, the QA programs for CAO, WID, SNL, and LANL adhered to the requirements of the NQA standards. Additional audits verified that QA programs adhering to the NQA standards had been established and executed for the single expert judgment elicitations considered so far, the qualification of existing data programs including the 1996-1997 peer review activities, and parameter traceability.

Recommendation: The EPA should review internal EPA documents relating to the promulgation to ensure that the underlying reasoning behind each §194.22 criterion has been adequately addressed for the information presented in the CCA.

2.14 MISCELLANEOUS CONTAINMENT REQUIREMENT ISSUES

2.14.1 Beyond 10,000 Years

Although the EPA standards require demonstration of compliance only for 10,000 years, some partial calculations performed by the EEG indicate that higher releases may be predicted beyond that period (see Section 2.9.3 of this report). There is no strong justification for stopping the calculation at 10,000 years. The EPA provided the following reason for selecting this time period (U.S. EPA, 1985, p. 38070):

> A period of 10,000 years was considered because that appears to be long enough to distinguish geologic repositories with relatively good capabilities to isolate wastes from those with relatively poor capabilities. On the other hand, this period is short enough so that major geologic changes are unlikely and repository performance might be reasonably projected.

The NEA/IAEA International Review Group (NEA/IAEA, 1997) made the following comment on this subject:

> The IRG was surprised that it did not find descriptions or arguments in the CCA indicating the possible performance of the WIPP facility beyond the end of the 10,000 year regulatory period. Such descriptions or arguments, including an indication of the mechanisms, likelihood, timing and possible maximum of impacts at longer times, would be an important element of performance assessment in most other countries.

While EEG agreed with the 10,000 year cut-off point in the development of the standards, we now recommend performance of representative calculations to assess the behavior of the repository beyond 10,000 years to enable comparison with other countries and conformance with the NAS Committee Conclusions on the High Level Waste Yucca Mountain Program.

2.14.2 Effect Of ERDA-9

The EPA has "screened out" (U.S. EPA, 1997c, p. 58801; 1997b) the potential effect of the existence of borehole ERDA-9, which is located only 28.5 meters (93.5 ft) east of the surface projection of the north-south drift E300 of the WIPP underground. The EPA concludes:

> ERDA-9 did not penetrate an area that will become a waste panel and DOE has indicated that abandoned boreholes more than a meter away from the waste can be screened out of PA due to low consequence. EPA agrees with DOE'S assessment that these boreholes are not significant to performance of the disposal system and can be screened out of PA.

The CCA argument for screening out the potential effect of ERDA-9 on the disposal system is presented in Appendix SCR 3.3.1.42 of the CCA, which refers the reader to an analysis conducted as a part of the WIPP 1991 performance assessment (Sandia, 1991/1, Appendix B, pp.26-27). This analysis was conducted by the DOE in response to a question raised by EEG in 1990 about the extent of the Disturbed Rock Zone (DRZ) and the permeability of Marker Bed 139. The analysis concluded that if permeability value difference of three orders of magnitude is assumed between a DRZ and the adjacent intact rock, then the bore hole flow rates from the two zones are markedly different. This is, of course, something to be expected. The questions to be asked and the issues to be considered before the effect of ERDA-9 can be written off, are:

1. How far is ERDA-9 from the drift E-300 *at the repository level?* Boreholes are seldom vertical; they deviate. For example, the borehole H-19-B-4, drilled under strict specifications for hydrologic and tracer testing of the Culebra aquifer in 1995-96, deviated 9.5 meters (31 ft) in 229 meters (752 ft) depth. At that rate, a borehole drilled to 655 meters (2150 ft) depth of the repository may deviate 27 meters (89 ft). Could ERDA-9 be very close to E-300 at the repository level?

2. How far does the DRZ of E-300 extend?

3. Whether or not there is pressurized brine reservoir underlying ERDA-9 is not definitely known,

although there is good reason to suspect it. ERDA-9 penetrated the Castile Formation for 17 meters (56 ft). The borehole WIPP-12 was drilled in 1978 to penetrate 14.7 meters (48.3 ft) into the Castile, and encountered pressurized brine when drilled an extra 74 meters (242.4 ft) in 1981.

4. How will ERDA-9 be sealed? Appendix SCR, Section 2.3.8.2, of CCA, states:

> WIPP investigation boreholes will be sealed using materials and designs in accord with industry standards for the Delaware Basin. A survey of plugging practice (Appendix DEL) shows that the majority of boreholes have a plug below the water-producing zones in the Rustler and a plug at the top of the Bell Canyon. Drilling and abandonment procedures may lead to additional plugs within the Salado. A few boreholes (2 percent of those surveyed), however, have a continuous plug of salt-saturated cement from the top of the Salado to the top of the Bell Canyon. ERDA-9 will be sealed in a similar manner. Other WIPP investigation boreholes will be plugged according to regulatory requirements and standard industry practice. The DOE has committed to plug with cement the portion of these boreholes that penetrate the Salado.

Why is EPA not requiring at least a special plugging procedure for ERDA-9 and other boreholes that penetrate the repository horizon within the WIPP site?

2.14.3 Brine Seepage into the Shafts

The EPA was concerned about the potential for seepage of brine into the shafts in the Salado Formation zone to be occupied by compacted salt plug. Attachment 1 of TSD III-B-3 (U.S. EPA, 1997g) is a trip report of inspection of the air intake shaft by EPA to verify the DOE statements concerning the lack of observable brine inflow in the lower Salado where the compacted. The inspection report concludes, “The air shaft inspection did not result in observations of any current brine seepage, as no areas appeared to be wet and no brine was observed.” It is common knowledge that the rate of brine inflow from the Salado marker beds is low enough that brine dries up almost instantly due to ventilation in the WIPP mine. This would certainly be expected in the air intake shaft. If the rate of water inflow is large enough, as is being observed in the WIPP exhaust shaft at the level of Santa Rosa and Dewey Lake Formations for the past several years, then even a large blast of air does not completely dry up water. As far as brine inflow from the Salado Formation is concerned, the presence of salt encrustations (efflorescences) clearly indicates current brine seepage. The inspection team's conclusion therefore simply indicates the absence of understanding of the mechanics of brine drying up in the air intake shaft, rather than the absence of brine inflow.

2.14.4 Iron in the Repository

There is a curious response by the EPA to the question of the amount of additional iron that may be introduced in the WIPP repository through rock bolts and other ground control and roof support system (U.S. EPA, 1997b, CARD14-95). Corrosion of iron in the presence of brine in the repository is expected to produce hydrogen. For at least the past 10 years, the question of gas production in the repository has been a concern and it is common knowledge that reduction of the amount of iron in the repository will help meet compliance with the EPA standards and is therefore a desirable goal. The EPA should therefore explain the following response:

> The amount of iron introduced into the disposal system by rock bolts is inconsequential since there is no upper limit on the amount of iron that can be emplaced in the repository. The DOE did specify a minimum amount of iron that must be emplaced into the repository withine (sic) Appendix WCL, Table WCL-1, which is based on the quantity of iron within the waste containers to be emplaced at the WIPP and does not rely (sic) the amount of iron contained in the roof support system to meet this minimum requirement. (U.S. EPA, 1997b, CARD 14-95).

Does EPA now believe in a *minimum* amount of iron that must be emplaced in the repository?

3.0 ASSURANCE REQUIREMENTS

3.1 INTRODUCTION

The EPA standards (U.S. EPA, 1993) contain a set of assurance requirements to provide the additional confidence needed due to the long period of time of concern and the uncertainties associated with the decision to dispose of waste without practical possibility of retrieval. The philosophy of the Assurance Requirements is clearly stated in the "Overall Approach of the Final Rule" (U.S. EPA, 1985, p. 38072), as follows:

> In contrast to the containment requirements, the assurance requirements were developed from that point of view that there may be major uncertainties and gaps in our knowledge of the expected behavior of disposal systems over many thousands of years. Therefore, no matter how promising the analytical projections of disposal system performance appear to be, these materials should be disposed in a cautious manner that reduces the likelihood of unanticipated types of releases. Because of the inherent uncertainties associated with these long time periods, the Agency believes that the principles embodied in the assurance requirements are important complements to the containment requirements that should insure that the level of protection desired is likely to be achieved.

During the promulgation of the original standards (40 CFR 191) in 1985, the EPA considered an additional assurance requirement that called for releases to be kept as low as reasonably achievable (ALARA) even when the numerical containment requirements have been complied with. This proposed requirement was deleted by EPA from the final rule for two reasons (U.S. EPA, 1985, p. 38072):

> First, NRC's 10 CFR Part 60 implemented the multiple barrier principle by requiring very good performance from two types of engineered components: a 300 to 1000- year lifetime for waste packages during which there would be essentially no expected release of waste, and a subsequent long-term release rate from the waste form of no more than one part in 100,000 per year....(and) Second, the DOE has included a provision in its site selection guidelines (10 CFR 960) that calls for significant emphasis to be placed on selecting sites that demonstrate the lowest releases over 100,000 years compared to the other alternatives available.

Neither of these provisions apply to WIPP and the net result for the TRU waste is that the DOE has argued for the minimum requirements rather than design for ALARA. EPA is proposing to certify WIPP on the basis of a very narrow interpretation of the assurance requirements without acknowledging the history of promulgation and the philosophy behind it.

There are six assurance requirements included in the standards (U.S. EPA, 1993). The following is the EEG assessment of the EPA's proposed rule for each of these.

3.2 ACTIVE INSTITUTIONAL CONTROLS

Title 40 CFR 191.14 (a) requires maintenance of active institutional controls for as long a period of time as is practicable after disposal, but credit in performance assessment may not be taken for more than 100 years. The DOE has proposed controls for 100 years and has assumed no drilling in the repository for that period. The EEG agrees with the EPA's finding for this requirement, but recommends that if in the final rule EPA finds WIPP to be in compliance with the standards and proposes to grant certification, oversight by the federal (other than DOE) and state authorities should be required to ensure vigorous implementation of the active institutional control.

3.3 MONITORING

Title 40 CFR 191.14 (b) requires disposal systems to be monitored both pre- and post-closure to detect any substantial or detrimental variations from expected performance. The monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and should be conducted until there are no significant concerns to be addressed by further monitoring.

Specific criteria to be met are outlined in 40 CFR 194.42 and require any compliance application to document and substantiate the decision not to monitor a disposal system parameter because the parameter is considered to be insignificant to the containment of waste in the disposal system or the verification of predictions about the future performance of the disposal system. The proposed criteria did not contain a mechanism whereby DOE could decide not to monitor a particular disposal system parameter on the basis that DOE considered it to be unimportant to the containment of waste or to verify predictions about future performance of the disposal system. Hence, EEG never had the opportunity to comment on this change that was effected in a meeting between EPA, DOE, and OMB and incorporated in the final criteria.

DOE has chosen to exclude from monitoring all parameters of interest in the repository during the pre-closure phase (excluding stress and deformation measurements and radioactivity in air) by qualitatively evaluating their significance in shifting either the probability or the consequence in calculations for the containment requirements. EPA has accepted the CCA analysis for this assurance requirement.

The reason for including the assurance requirements in the standards was the inherent uncertainty in the calculations of releases for 10,000 years. The benefits from the assurance requirements were never intended to be quantified. It was recognized that there could be no clear yardstick to measure the benefit of a marker or the detriment to confidence in predicting the behavior over 10^4 years if markers were not used. The same logic applied to records maintained by institutions and the benefits of the ability to retrieve waste. The approach allowed by EPA in the final criteria is to permit DOE to assess the usefulness of monitoring by a qualitative evaluation of the impact of improving our knowledge of the potential behavior of the repository. This is contrary to the intended purpose of the assurance requirements. It does not make sense to exempt DOE from the assurance requirement for monitoring based on a qualitative evaluation that depends on the containment calculations being correct.

Chapter 7.2 of the CCA evaluated various parameters including those listed in 194.42 and concluded that there was little merit in obtaining measurements of changes in various parameters since changes occurring over a short time period may not be representative of the steady state conditions that would exist over long time periods. DOE points out that obtaining data for a 35 year period is of little value in extrapolating results over a 10,000 year regulatory period. For years, DOE pursued the desire to conduct an experimental program with waste at WIPP and argued that obtaining 5 years worth of data would be effective in confirming the predicted behavior of the TRU waste.

DOE identified 10 parameters needing monitoring in the pre-closure period and only 5 of those worthy of monitoring in the post-closure period. EPA concurred. The post-closure monitoring parameters are:

- Culebra groundwater composition
- Culebra change in groundwater flow
- Probability of encountering a Castile brine reservoir
- Drilling rate
- Subsidence measurements

EEG believes there are a number of parameters that can be monitored in both the pre- and post-closure period that could help verify predictions of the future behavior of the disposal system.

1. Drilling practices in the Delaware Basin of air drilling, CO_2 injection and other underbalanced

drilling should be monitored as well as borehole diameters and mining practices such as shaft diameters.

2. Continued investigation of non-invasive techniques to monitor brine migration, gas generation and radionuclide movement. While DOE acknowledges (U.S. DOE, 1996c, page 7-50) these remote techniques to determine characteristics of the earth have been well established in measuring resistivity, acoustic velocity, magnetism, density, temperature, moisture control, and radioactivity, they conclude that changes in the repository will be too small or too slow to be detectable using remote techniques. EEG sees no evidence to warrant this conclusion.

3. Prior to sealing Panel 1, remote sensors could be placed in the rooms of Panel 1 to measure moisture content, CO_2, room closure or other parameters and detectors hooked to cables located outside Room 1. One could obtain 10 years worth of highly detailed data on the actual behavior of the repository.

4. Non-invasive detectors could be located outside the Panel 1 seal to monitor parameters inside Panel 1 rooms. One could obtain 35 years worth of data on the actual behavior of the repository.

5. Groundwater quality of the Dewey Lake and Santa Rosa Formations be monitored.

Note that the U.S. Nuclear Regulatory Commission (U.S. NRC) plans to require DOE to monitor post-closure at the Yucca Mountain High Level Waste Repository {10 CFR 60.51 (a)(1)}. The Performance Confirmation Program outlined in Subpart F, 40 CFR 60.140 through 60.143 establishes detailed programs to monitor the condition of the waste packages as well as subsurface changes during construction and waste emplacement operations. The NRC Subpart F requirements apply to the pre-closure conditions. EEG is unaware that DOE finds such a request unreasonable for the high-level waste repository. EEG believes that DOE should be required to pursue non-invasive long-term monitoring programs during the operational period as a condition for approval, and a major evaluation should be undertaken prior to the first recertification.

3.4 PASSIVE INSTITUTIONAL CONTROLS

Title 40 CFR 191.14 (c) requires designation of the repository site by the most permanent markers, records, and other passive institutional controls (PIC) practicable to indicate the dangers of the wastes and their location. The EPA proposes to require WIPP to implement the system of PICs but proposes to deny taking credit for PICs in the performance assessment for the containment requirements. The EEG agrees with this determination of denying credit for PICs for reasons stated by the EPA in U.S. EPA (1997c), as well as for reasons that EEG has previously submitted to the EPA (see Appendix 8.2-Passive Institutional Controls).

3.5 ENGINEERED BARRIERS

Title 40 CFR 191.14 (d) requires use of both engineered and natural barriers in the repository design. The CCA proposed a chemically-buffering magnesium oxide backfill as the only engineered barrier, and the EPA has accepted in the proposed rule the DOE (U.S. DOE, 1996c) proposal to satisfy this assurance requirement. The EEG view is that while there are still some questions about the efficacy of the chemical buffer aspect of the magnesium oxide (MgO) backfill (see section 2.3 and Appendix 8.4 of this report), this engineered feature has been selected primarily to enable DOE to use numerical values of certain parameters in the containment requirement calculations. The MgO backfill may not therefore be considered to satisfy this assurance requirement in a strict sense of the philosophy of these requirements. Incorporation of backfill in the WIPP design is nevertheless a good idea and the EEG has been recommending a salt/clay mixture as backfill for years. A pure MgO backfill does not have the benefit of the chemical retardation of radionuclides that clays afford, but may help keep the repository chemical environment stable. The EEG would prefer addition of clays such as commercially available bentonite to the backfill, but is willing to accept emplacement of MgO backfill for the sake of operational ease and efficiency.

The EEG disagreement with the EPA on this issue concerns the lack of incorporation of engineered barriers that would provide additional assurance beyond helping in the calculations to satisfy the containment requirements. With respect to the engineered barriers as an assurance requirement, the "Overall Approach of the Final Rule" (U.S. EPA, 1985, p. 38072) states:

> Designing disposal systems to include multiple types of barriers, both engineered and natural, reduces the risks if one type of barrier performs more poorly than current knowledge indicates.

The CCA (U.S. DOE, 1996c, Sec. 3.3) describes four types of engineered barriers in the design of the WIPP disposal system: (1) Shaft Seals, (2) Panel Closures, (3) Backfill around the waste, and (4) borehole plugs. EEG does not consider any of these to be engineered barriers, for the following reasons:

3.5.1 Shaft Seals

Shaft seals are at best an attempt to undo the damage done to the natural environment when the shafts were excavated, and therefore cannot be considered to be an engineered barrier as distinct and *complementary* to the natural barriers.

Note that the 40 CFR 191.12 definition of a "Barrier" includes the following examples of engineered barriers, but does not include "shaft seals".

> ... A canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides.

The repository standards for the high-level nuclear waste repository (10 CFR 60) specifically exclude shaft seals from engineered barrier system. "Engineered Barrier System" is defined in 10 CFR 60.2 as:

Engineered barrier system means the waste packages and the underground facility.

and

Underground facility means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals (underline added).

3.5.2 Panel Closures

Like the shaft seals, panel closure systems (separation of waste panels by engineered structures) cannot be considered to be engineered barriers because they too can at best be imperfect attempts to restore the original natural system. Panel seal is not included in the examples of engineered barrier in the EPA definition (40 CFR 191.12).

The Marker Bed 139 lies directly below the WIPP repository and is connected to the floor of the waste rooms through extensive fractures, floor upheaval and milling of the floors. Water (with anomalous lead content acting as a tracer) seeping down from the exhaust shaft has moved 400 ft through the marker bed from the base of the air exhaust shaft to the waste handling shaft in a short period of time during 1995-96. This pervasive marker bed would not allow effective separation of the panels unless the entire floor of the repository is dug down 10 ft and grouted.

According to the CCA (U.S. DOE, 1996c, p. 3-27, lines 19-20), "The panel closure system was not designed or intended to support long-term repository performance." How then can it be considered an engineered barrier for the long-term performance?

3.5.3 Backfill Around the Waste

The DOE plans to put sacks of magnesium oxide (MgO) over and around the waste drums to try to control the future chemical conditions in the repository. The expectation is that MgO will react with the carbon dioxide (CO_2) that is produced from microbial action in the repository. Removal of CO_2 will result in alkaline conditions in the repository. Since the experimentally determined solubilities of radionuclides are lower in alkaline (high pH) conditions, the emplacement of MgO and its postulated effect allows assumption of lower solubility values in the CCA. This assumption results in lower postulated releases to the accessible environment and thus helps in showing compliance with the Containment Requirements (40 CFR 191.13) of the EPA Standards.

Since the publication of the CCA, the DOE has argued that the MgO is not needed for showing compliance with the Containment Requirements because the mean CCDF without MgO, although showing higher releases than "with MgO", still is within the compliance limits. Such an argument is based on a partial calculation without altering other assumptions and input parameters, and therefore appears meaningless. The fact remains that the purpose of including MgO in the WIPP repository is to control the chemical conditions in the WIPP repository to allow assumption of lower actinide solubility values. It may therefore satisfy a need for the Containment Requirement of the Standards, but does not provide *complementary* added assurance visualized by the Assurance Requirements (40 CFR 191.14).

3.5.4 Borehole Plugs

Since the stated requirements for plugging the boreholes (U.S. DOE, 1996c, Section 3.3.4, Figure 3-10) are much less stringent than the shaft seals, the borehole plugs have a lesser claim as engineered barriers than the shaft seals. The EPA Standards (40 CFR 191.12) do not include borehole plugs as an example of engineered barriers. The NRC specifically excludes borehole seal as part of an engineered barrier system (see the quote under Shaft Seals section above). Hence, the borehole plugs should not be considered to be an engineered barrier.

Incidentally, the DOE's CCA - Figure 3-9 (U.S. DOE, 1996c, "Approximate Locations of Unplugged Boreholes") does not include two deep abandoned oil and gas wells that are located within the WIPP site: Badger Unit Federal in Section 15 (between WQSP-3 and H-5 in the northwest part of the WIPP site), and Cotton Baby Federal in Section 34 (east of H-11 in the southeast corner of the WIPP site).

3.5.5 Waste Processing and Repackaging

Additional confidence in predicting the behavior of the waste over 10,000 years can be obtained by processing the waste. Hence, EPA should encourage the DOE to process the waste before shipment to WIPP. TRU waste is highly heterogeneous and there are no limits on the allowable particle size of the waste. The Nuclear Regulatory Commission (10 CFR 61) requires a 300 year waste-form or container longevity for class B or class C *low-level* waste, whereas there are no requirements for the TRU containers or the waste-form in 40 CFR 191. Moreover, the DOE proposed action in the WIPP 1997 Environmental Impact Statement only commits to meeting the Waste Acceptance Criteria for acceptance of waste at WIPP. The DOE **preferred alternative**, published in the 1997 Final Waste Management Programmatic Environmental Impact Statement for Managing, Treatment, Storage and Disposal of Radioactive and Hazardous Waste, is to **treat** and store at the sites where it is generated prior to shipment to WIPP.

The recommendation to treat the waste before shipping to WIPP should be easier to accomplish because several of the DOE's waste generator sites are planning to process and/or repackage the waste before shipping to WIPP anyway, for other reasons, as described below. The EPA's recommendation will result in an orderly and coordinated decisions on this matter throughout the DOE weapons complex, and will make WIPP safer.

- According to the September 1997 WIPP Final Supplemental Impact Statement (U.S. DOE, 1996d), 27,000 m^3 of alpha emitting low level waste at INEEL will be processed to convert it to TRU waste.

The information for the following processing and repackaging plans is derived from the National TRU Waste Management Plan (U.S. DOE, 1997c).

- INEEL plans to process all the existing and projected TRU waste except for 15,000 drums (3,000 m^3) to meet the INEEL/State of Idaho agreement, which amounts to processing 79,600 m^3 - 3,000 m^3 = 76,600 m^3 of waste.

- ANL-E plans to treat and stabilize all the 203 m^3 existing and newly generated CH-TRU waste.

- Hanford plans on repackaging most of its 16,127 m^3 of CH-TRU waste.

- Rocky Flats Plant will process most of the plutonium residues and all of the scrap alloy since plutonium concentrations exceed the DOE limits. About half the other TRU waste will be processed and repackaged.

- The Plutonium-238 heat source wastes at Savannah River exceed the hydrogen gas limits imposed by NRC and will require treatment or an easing of the regulations for a less stringent flammable limit or the use of hydrogen getters in the transportation containers.

- All the 1097 m^3 CH-TRU waste at ORNL will be processed with a 50% volume reduction.

- SRS plans to process and repackage 9,525 m^3 of the existing 11,725 m^3 of CH-TRU waste.

In summary, of the existing 104,400 m^3 of CH-TRU waste, DOE has plans to treat or repackage 88,900 m^3 or 85%. Of the 15,500 m^3 not being processed, 3,000 m^3 is intended for shipment to meet a scheduled commitment between DOE and the State of Idaho. The EPA should recognize DOE's efforts in stabilizing the waste and encourage DOE to also fix the yet-to-be generated waste.

3.6 RESOURCE DISINCENTIVE REQUIREMENT

Title 40 CFR 191.14 (e) requires that areas with natural resources should be avoided in selecting a site for a TRU waste repository, unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future. The WIPP site is located in the middle of an area with extensive history of exploitation of potash, oil and gas, and is surrounded by hundreds of currently producing oil and gas wells, as well as several currently producing potash mines. It is expected that the mining and drilling activity will continue around the WIPP site for the foreseeable future. If the WIPP site had not been withdrawn for exclusive use by DOE, almost certainly there would have been a number of exploratory oil and gas wells and potash mines at the site by now. The EPA has proposed to determine that the WIPP meets this compliance requirement on the basis of the results of the calculations for the containment requirements.

The EEG believes that in allowing the resource disincentive requirement of the EPA standards to be satisfied if the numerical containment requirements (40 CFR 191.13) are satisfied (through 40 CFR 194.45), the EPA deviated from the basic philosophy of the multiple barrier "belt-and-suspender" approach inherent in the assurance requirements of the standards. Faced with the *fait accompli* of promulgation of 40 CFR 194, the EEG recommended (Neill et al., 1996) that at least the actual conditions at the site related to the presence of natural resources be fully and conservatively assumed in projecting compliance with the numerical containment requirements. This does not appear to have been done in the CCA, judging from the DOE resistance to consideration of fluid injection, air drilling, and mining scenarios. The other suggestion made by the EEG (Neill et al., 1996) is to compensate for siting the repository in a mineral resource rich area by incorporating robust engineered barriers in the WIPP's design. The DOE has proposed Magnesium Oxide backfill as an engineered barrier, but that is needed for assuming low actinide solubility to show compliance with the containment requirement. The "containment" and the "assurance" requirements of the EPA standards thus have not been kept separate, as was intended by the EPA standards, 40 CFR 191.

The EEG recommends that full consideration of the effects of the presence of natural resources be incorporated as suggested in Sections 2.5, 2.6, and 2.8 of this report, in a new PAVT, and the engineered barriers be incorporated as suggested in Section 3.4 above.

3.7 RETRIEVABILITY

Title 40 CFR 191.14 (f) states, "Disposal systems should be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal." The EPA explained in the preamble to the originally proposed rule (U.S. EPA, 1985, p. 38082; September 19, 1985) that the recovery of waste does not have to be "easy or cheap".

In response to this requirement, the CCA (U.S. DOE, 1996c) presented a five phase approach from planning to decontamination and decommissioning of the facility, and the EPA proposes to find WIPP in compliance of this requirement. As a practical matter, however, the EEG believes that attempts to remove the waste from the repository, even 10 years after first emplacement, will be so hazardous and expensive that it is not a reasonable option. The EPA and the DOE should clearly acknowledge that fact.

4.0 GROUNDWATER PROTECTION REQUIREMENTS

Subpart C of 40 CFR 191 contains the Environmental Standards for Groundwater Protection. Section §191.24 specifies that undisturbed performance of the repository shall not cause the limits specified in 40 CFR part 141 to be exceeded during the 10,000 year regulatory period in any underground source of drinking water (USDW). An aquifer must be able to supply sufficient quantity of water to a public water system and to contain less than 10,000 milligrams of total dissolved solids per liter (§191.22).

Compliance with these requirements requires that USDWs about the WIPP Site be identified, that existing concentrations of radionuclides in these USDWs be estimated, and the increased radionuclide concentrations and doses from the undisturbed performance of the repository be determined.

Previous EEG Comments

The DCCA (U.S. DOE, 1995c) did not address groundwater protection requirements and consequently EEG did not make comments in our review of the DCCA (Neill, et al., 1996). EEG has not made any previous written comments to DOE or EPA on Chapter 8 of the CCA (U.S. DOE, 1996c).

EPA Response to Chapter 8

EPA mostly concurred with DOE's evaluation of the location of possible USDWs. However, in a December 19, 1996, letter EPA did specify that "the CCA needs to include appropriate maps of USDWs using Plan views with information such as township, range, and estimated latitude and longitude of the center of the USDW." A map was provided in DOE's February 27, 1997, response to EPA's request for additional information. DOE did not provide a location of the estimated center of the USDWs because of the contention that sufficient data were not available.

EPA accepted DOE's map of USDWs as adequate without location of their centers. Also, EPA concluded that even though DOE calculated a maximum total alpha radioactivity concentration of about 9 pCi/ℓ (compared to the limit of 15 pCi/ℓ) the potentially large uncertainty was not a problem because these concentrations were in anhydrite formations and not USDWs.

EEG Evaluation

EEG has several concerns or questions about DOE calculations or assumptions and about EPA's Compliance Review.

USDW Designation. The assumption by DOE that a 5 gallon per minute pumping rate was necessary to supply 25 persons is non-conservative. Water consumption may average 282 gallons per capita per day in nearby communities where there is a water system that can supply additional water for lawns, gardens, swimming pools, etc. However, in a rural community where nearby water sources are limited, persons can live quite well on 100 gallons per capita per day. Thus, a pumping rate of 2 gpm should be adequate for 25 persons. The pumping rate criterion did not actually affect DOE's designation of USDW areas because pumping rate data were usually not available and the boundaries were selected on the basis of the total dissolved solids criteria.

EEG is satisfied with the boundaries of USDWs for the Culebra, Dewey Lake, and Santa Rosa aquifers that are shown in Figure 1 of DOE's February 27, 1997, submittal.

Radionuclide concentrations in USDWs from undisturbed releases. DOE relied on the analysis performed for the individual protection requirements to show that the maximum concentration of alpha emitting radionuclides and the allowable dose from beta and gamma radiation was not exceeded. The concentration from the maximum realization was 6.61 pCi/ℓ for ^{239}Pu + ^{230}Th + ^{234}U. These concentrations were determined from BRAGFLO flows and the NUTS code for radionuclide transport and are in anhydrite beds and not an USDW. A different calculation scheme was used to estimate the ^{226}Ra concentration. This calculation led to an estimated ^{226}Ra concentrations of 2 pCi/ℓ which is 2 orders of magnitude greater than the maximum concentration of its parent, ^{230}Th in the

BRAGFLO/NUTS calculation. It seems apparent that these two methods of calculation are unrelated.

EEG believes the concentrations of radionuclides due to an undisturbed release from WIPP in any possible USDW will be somewhat less than the Maximum Concentration Limits (MCLs) in 40 CFR 141. This conclusion is based on the belief that while some contamination could occur between anhydrite beds and USDWs the amount of dilution that would be needed in order to maintain a TDS concentration in a USDW aquifer below 10,000 mg/ℓ would more than offset uncertainty in estimating radionuclide concentrations.

Radionuclide concentrations in uncontaminated USDWs. 40 CFR 191.24 states that any release from undisturbed performance shall not cause the levels of radioactivity in USDW to exceed the limits specified in 40 CFR part 141. In other words, the releases from the repository should be added to the existing radionuclide concentrations to determine compliance. This point was contested in comments on the proposed rule and EPA's decision to include both existing and added concentrations was explained in the preamble to the rule. Basically, EPA doesn't want to have any degradation in a USDW that has concentrations at or above MCL values.

The final 40 CFR 194 and the Compliance Application Guidance (CAG) (U.S. EPA, 1996a) are vague about whether existing concentrations of radionuclides need to be determined and added to estimated concentrations from undisturbed releases in order to show compliance. No relevant discussion was found in the preamble to 40 CFR 194 or in the Background Information Document.

The CCA provided no information on existing concentrations of radionuclides in the possible USDWs and EPA did not ask for this information. Natural system compliance with the MCLs should not be assumed. EEG measured radionuclide concentrations in 3 Dewey Lake wells just south of the site in 1989 and 1990 . One of the four samples measured 37 pCi/ℓ gross alpha, 13.6 pCi/ℓ uranium, and 2.4 pCi/ℓ ^{226}Ra + ^{228}Ra (Kenney and Ballard, 1990).

EPA needs to either obtain existing radionuclide concentrations in the possible USDWs in order to show compliance with 40 CFR 191.24 or explain why this requirement is not applicable.

5.0 INDIVIDUAL PROTECTION REQUIREMENTS

Section §191.15 of 40 CFR 191 provides that disposal systems "shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts)." The Individual Protection Requirements were addressed by DOE in Chapter 8 of the CCA.

Previous EEG Comments

The DCCA did not provide dose calculations to determine if the individual protection requirements had been met. Consequently, EEG had no comment on this requirement in our review of the DCCA (Neill et al., 1996). EEG has not made any previous written comments to DOE or EPA on Chapter 8 of the CCA.

EPA Response to Chapter 8

In the CCA DOE concluded that the only mechanism for undisturbed releases and a dose to an individual was from migration of brine from the repository in anhydrite marker beds to the accessible environment. This contaminated brine was pumped to the surface and diluted to decrease total dissolved solids to 10,000 milligrams per liter. The individual was assumed to drink 2 liters per day of this diluted water. The realization with the highest concentration of radionuclides (out of 300 realizations) was used for the dose calculation.

EPA requested that DOE provide analyses of other exposure pathways beside the drinking water pathway evaluated in Chapter 8 of the CCA. DOE provided this analysis in their February 27, 1997 response to EPA's request for additional information. The additional pathways scenarios analyzed were: (1) farm family inhalation; (2) farm family ingestion; and (3) cattle rancher. DOE dose estimates for the maximum realization were 0.47 mrem for drinking water and 0.46 mrem from ingestion (the other scenario doses were negligible).

EPA also made their own Dose Verification Evaluation and included this Technical Support Document (U.S. EPA, 1997k) with the proposed rule. Pathways evaluated were drinking water; crop, soil, meat and milk ingestion; inhalation; and direct radiation. EPA calculated doses of 0.49 mrem per year from drinking water and 0.16 mrem for all other pathways.

EPA agreed that the DOE scenario assumptions were conservative and actually unlikely. Also, that the CAG (U.S. EPA, 1996a) requirements were fully met. Therefore, they concurred in the adequacy of DOE's Individual Protection Requirement evaluation.

EEG Evaluation

The EEG checked both DOE's and EPA's dose calculations. Agreement was within 5%.

CCA calculations of the concentration and quantity of radionuclides reaching the accessible environment in the anhydrite interbeds were taken as a given by EPA. EEG has not checked these calculations either but they appear reasonable. Also, the limited quantity of contaminated water calculated to reach the accessible environment (a maximum of 216 m^3) was not invoked by DOE or EPA in their calculations. This limited quantity of contaminated water would preclude EPA's calculated 30-year radionuclide buildup in soil (which contributes less than 1% of the other pathways dose).

We consider two inhalation and soil ingestion pathways to be more likely than those considered by DOE and EPA. These are: (1) resuspension of solids from undiluted brine used for dust control about a residence; or (2) resuspension of solids from a mud pit where the contaminated brine has evaporated. The brine could be in the mud pit as a result of an aquifer pump test, an oil or gas borehole, or as a residue from a water treatment process (such as reverse osmosis). However, these scenarios result in estimated doses that are less that 0.1 mrem/y. So, these scenarios, though perhaps more reasonable, lead to lower doses than calculated by DOE and EPA.

EEG agrees that this requirement has been adequately and conservatively evaluated. We consider this to be a closed issue.

6.0 EVALUATION OF EPA'S RESPONSES TO EEG'S COMMENTS

The EPA has provided responses to some of the EEG comments on the CCA provided to the EPA before the March 17, 1997, deadline. These responses are found at the end of each Compliance Assessment Review Document (U.S. EPA, 1997b). References have been made to these responses in the relevant chapters in this report. For the sake of completeness, the EEG review of these responses are grouped together in this chapter.

Section 194.14 (CARD 14)

Issue 14.T: The probability of encountering a brine reservoir during drilling and the reservoir's potential volume are underestimated.

103. The CCA assumed that the probability of encountering a brine reservoir is a function of reported brine encounters expressed as a percentage of total boreholes drilled. The problem with this assumption is that drillers are not required to report brine encounters; moreover, drillers tend not to report such encounters unless they result in significant delays or cause other problems during operations. Thus, the eight percent brine encounter rate used in the CCA dramatically understates the actual rate, which probably lies somewhere between 50 and 100 percent. (103)

525. The EEG does not find the CCA reservoir volume assumption of 32,000 to 160,000 m^3 to be justified. (525) (II-H-12.4)

EPA response to Issue T:

EPA found that DOE's representation of brine pocket occurrence probability and brine pocket size/volume in the CCA were not consistent with available information. EPA directed DOE in letters dated March 19, 1997 (Docket A-93-02, Item II-I-01, enclosure 3) and April 25, 1997 (Docket A-93-02, Item III-I-27) to conduct new performance assessment modeling that includes modified parameter values. EPA requested that the brine pocket probability be modified to a range from 1 percent to 60 percent, and that this occurrence be sampled rather than a fixed value of 8 percent. In addition, EPA requested that the parameters regarding rock compressibility and porosity (e.g. Castile COMP_RCK), as well as how the brine pocket volume is sampled, be modified in the mandated Performance Assessment Verification Testing (DOE, 1997b and 1997c). This approach effectively modified the sampled brine pocket volume to include more representatively the possibility of higher brine pocket volumes, including that of WIPP-12. As a result of the PAVT, EPA found that the original brine reservoir characteristics were, in fact, acceptable. For more discussion on this topic, also see this CARD, section 14.B.5, EPA's Technical Support Document for Section 194.14: Content of Compliance Certification Application (EPA, 1997a) and the Technical Support Document for Section 194.23: Parameter Justification Report (EPA, 1997e).

EEG assessment of EPA response to Issue 14.T

The Performance Assessment Verification Test has demonstrated that the brine reservoir characteristics have a large effect on predicted repository pressure and brine saturation. The EEG believes that the Performance Assessment Verification Test is a valuable set of calculations that were needed to demonstrate the robustness of the performance assessment calculations.

The characterization of the potential high pressure brine pocket used in the PAVT is much more accurate than the representation used in the CCA calculations. There are two parameters used in the PAVT that are still inaccurate. First, the PAVT uses a sampled pressure range of 11.1 to 16.5 MPa gage for the Castile brine, based on regional occurrences of brine, rather than the 12.6 MPa gage measured at WIPP-12. WIPP-12 brine almost certainly protrudes under the WIPP repository. However, it was found that the pressure range used in the PAVT leads to prediction of more and larger brine releases than the single value of 12.6 MPa (Rucker, 1998).

Secondly, there is poor justification for the 1% lower end of the EPA range for the probability of encountering a pressurized brine pocket. The 60% upper end is based on an electromagnetic survey of the WIPP site (U.S. DOE, 1996c, 2.2.1.2.2) that indicates brine is likely under about 60% of the repository. Most importantly, the probability of hitting brine under WIPP should be based on local WIPP information and not the entire Delaware basin. The calculated size of the WIPP-12 brine reservoir and the existence of boreholes around WIPP-12 that have not encountered brine in the Castile constrain the WIPP-12 reservoir such that the reservoir must extend under the repository (Neill, 1997d). The brine indicated by the electromagnetic survey must be part of the WIPP-12 reservoir. Hence, the probability of encountering brine should be modeled as 60%. Thus, the PAVT under represents the probability of encountering a brine reservoir while overestimating the effect of the reservoir.

Section 194.23 (CARD 23) Models and Computer Codes

ISSUE 23.A: Cuttings/Cavings and Spallings Model

97. The CCA fails to consider cavings that occur as the drill bit passes through the waste, cavings from particle impact, cavings from helical turbulent flow, and radioactive brine ejected before spallings.

EPA Resolution of comment 97

EPA disagrees with the comments. The cavings submodel rigorously considers the impact of helical laminar flow on cavings release by numerically solving a series of non-linear integral equations. Because of complexities in the turbulent flow regime, similar mathematical treatment is not possible and it is necessary to resort to empirical procedures. DOE accounts for the helical flow component in the turbulent regime by using a rotation factor (F) which increases the erosion as compared to that calculated by uniaxial flow (Docket: A-93-02, II-G-1, Volume V, Appendix CUTTINGS_S, WPO #37765, page 47). For radioactive brine to be ejected from an inadvertent human intrusion borehole which penetrates waste, two conditions must be met (Docket: A-93-02, II-G-1, Volume 1, Chapter 6, Section 6.4.7.1.1, page 6-152):

> *The waste must be under sufficient pressure to drive the drilling mud from the borehole (greater than 8 MPa). Mobile brine contaminated with radionuclides must be present.*

The direct brine release conceptual model as implemented with the BRAGFLO_DBR code addresses this issue of ejection of radioactive brine (Docket: A-93-02, II-G-5). The cavings model does not explicitly consider erosion from particle impact as the drill bit passes through the waste. Any such erosion would be of very short duration (about four minutes for fully compacted waste at a drilling rate of 50 ft/h). Borehole enlargement from particle impact would produce lower flow velocities for the drilling mud and reduce the erosion calculated by the cavings model. Consequently, EPA believes that any impact from this process is included within the range of calculated cavings releases.

EEG Assessment of comment 97.

The EEG concurs with EPA's assessment.

98. The spallings model assumes constant pressure, although blow-out is a phenomenon related to pressure differentials. There are several methodological problems with the experiments (e.g., no dimensional analysis, no vent sensitivity analysis, etc.). The model considers only particle dislodgment, not lifting or lofting. Limited parameters are sampled or calculated (e.g., particle diameter, but not waste permeability, cementation strength, drill bit diameter, or radioactive content of waste).

EPA Resolution on comment 98

EPA agrees that the spallings conceptual model was initially inadequate. However, these inadequacies result in higher releases. Since the Conceptual Model Peer Review Panel found the spallings model implemented in the CCA to be inadequate, DOE conducted a significant computational and experimental program as documented in Docket A-93-02, Item II-G-23. These new computational approaches include consideration of pressure transients. On the basis of this new material, the Peer Review Panel determined that the spallings model used in the CCA resulted in the calculation of release volumes which are reasonable and may actually overestimate expected releases (Docket: A-93-02, II-G-22, Conceptual Models Third Supplementary Peer Review Report, April 1997, page 12).

The new computational approach predicts extremely small spallings volumes for all gas pressures below lithostatic pressure. EPA has concluded that, since the spallings model in the CCA considers only particle dislodgement from the waste and not lifting or lofting of dislodged particles up the borehole, the approach taken by DOE is conservative. Larger particles dislodged from the surfaces of radial fractures in the waste will not be lifted 2150 ft to the land surface. In Docket: A-93-02, II-G-23, page 1-3, the tensile strength of saturated surrogates waste was measured to be 0.074 MPa while that of dry waste was 0.15 MPa. This may be compared to a value of 1 Pa used for the cementation strength in the spallings model. Thus the tensile strength in the spallings model was conservatively assumed to be several orders of magnitude lower than determined by tensile tests on waste surrogates. As discussed in detail in Section 1.2.3.2.4. of the '194.23 Technical Support Document- Models and Computer Codes, the use of a single value for the drill bit diameter is reasonable.

In the CCA, DOE chose to treat the radioactivity released by spallings as the average radioactivity in the repository (Docket: A-93-02, II-G-1, Volume 1, Chapter 6, Section 6.4.7.1, page 6-151) and based this position on the fact that the spallings model presumed that waste was eroded from fracture channels extending over a large portion of a waste room. In contrast, radioactive releases from cuttings and cavings were based on randomly sampling three of 569 waste streams for each intrusion. In this case the argument was made that cuttings/cavings removed only a localized volume of waste. Thus, the approach taken by DOE is consistent with the conceptual model in each case (ibid., page 6-189). It may further be noted that the CCDFs for waste volume removed by cuttings/cavings and spallings are about the same magnitude (see Figures 4.2.2 and 4.4.3, right frame, mean in Helton and Jow 1996, pages 4-6 and 4-22, Docket: A-93-02, II-G-07). Thus, if waste stream variability were incorporated into spallings releases, the results would be roughly comparable to those for cutting/cavings which as can be seen in Figure 4.2.3 (ibid., right frame, mean, page 4-6) are well below the EPA release limits. Since the average activity of the CH-TRU and the RH-TRU waste is essentially the same (ibid., page 4-1), and since the spallings model considers removal of waste from throughout an entire room, omission of RH-TRU waste from the spallings model will not have a significant impact on calculated releases.

EEG assessment of comment 97

The newer spallings model (Hansen et al., 1997) and subsequent peer review resolves this comment. However, the issue of an adequate spallings model remains. As shown in Section 2.4 of this report, the newer codes fail to model expected repository conditions.

This is still a major concern.

262b. The CCA fails to consider RH-TRU waste in the spallings scenario.

EPA Resolution on comment 262b

EPA agrees [sic]. EPA believes that combining the RH-TRU waste streams into a single volume-averaged stream is a reasonable modeling simplification. This is supported by the fact that the average activity in the RH-TRU and the CH-TRU waste is about the same while the probability of encountering CH-TRU is about seven times greater. Consequently cuttings releases are dominated by CH-TRU (Docket: A-93-02, II-G-07, Helton and Jow 1996, page 4-1).

DOE Response to issue

669 The conceptual models used to characterize the spallings and direct brine release processes were developed to describe the effects of rapid depressurization of large volumes of interconnected, homogeneous, and relatively permeable waste material. The models do not apply to the effects of rapid depressurization on the relatively small and relatively well isolated volumes anticipated for the RH-TRU waste. RH-TRU waste will be emplaced in boreholes in the halite walls of the waste disposal region. . .The volume of pressurized fluid available within a single RH-TRU canister will be far too small to displace the drilling fluid within the borehole, and therefore intrusions directly into an RH-TRU canister are very unlikely to result in a spall or direct brine release event. Intrusions into CH-TRU, waste near an RH-TRU emplacement borehole will draw spalled material and contaminated brine from the more permeable CH-TRU waste, rather than from the RH-TRU waste. It is therefore correct not to apply the spallings and direct brine release models to RH-TRU waste. (II-H-21.26)

670 DOE chose to model cuttings and cavings releases of RH-TRU waste using a single, average activity level for RH-TRU waste based on consideration of information available

in the Baseline Inventory Report (BIR) Rev. 2 (Appendix BIR of the CCA). Individual waste streams are reported for RH-TRU waste. Most of these waste streams represent small volumes of material, however, and the probability assigned to the penetration of many of these individual categories by an intrusion borehole would have been below the regulatory threshold of 10^{-3} in 10^4 yr. Rather than neglect these low-probability events, the DOE has included them in the analysis by lumping them, and their activity loads, into a single category with the other, more abundant RH-TRU waste that dominates the volume-averaged activity of RH-TRU waste used in the performance assessment. The activity levels that might be calculated by random combinations of large numbers of waste streams plus backfill would closely resemble the overall average activity. (II-H-21.27)

EEG assessment of EPA comment resolution

The EEG is satisfied that neglecting RH-TRU in spallings calculations and using a single waste stream to represent RH-TRU in the cuttings and cavings model are acceptable modeling approximations. The primary reasons for this assessment are that RH-TRU will be less that 1% by volume of the transuranic inventory of the repository and that the high activity levels in the RH-TRU waste are from fission products that will have significantly decayed in the first two hundred years of burial. While the present activity of RH-TRU waste varies many orders of magnitude, the transuranic content of the waste does not.

535 The spallings model is defined as gas driven entrainment of solid particles. The spallings model should include the effects of brine. (II-H-12.14)

EPA Resolution of Comment

EPA disagrees with the comment. Spallings occurs only if the pressure in the intruded waste panel exceeds 8 MPa. As the gas pressure increases, the brine saturation in a waste panel decreases (Docket: A-93-02, II-G-07, Helton and Jow 1996, page 5-1). Thus, at pressures where spallings can occur, less brine is available for release. In addition, the spallings model uses the average radionuclide concentration in the waste to develop the source term (ibid., page 4-7). If some radionuclides are dissolved in brine which is transported along with solid waste to the surface, this radioactivity will have been accounted for by the solid material since mass must be conserved. The spallings model addresses all the radioactivity as if it remained with the solids rather than partitioned between the solid and the brine. Direct brine releases in which brine flows up the borehole after intrusion are accounted for by the direct brine release model (Docket: A-93- 02, II-G-05). EPA believes that this "double counting" of solid spall releases and waste mobilized by brine overestimates releases from these mechanisms and therefore is adequate for use in PA and is conservative.

EEG assessment of EPA comment 535 resolution

In light of the newer spallings model (Hansen et al., 1997), the inclusion of brine release in the spallings model is a minor concern.

536 With the composition of the waste ranging from large pieces of metal to ash, it is unlikely that the waste will degrade to a uniform grain size. There has been no analysis to show that the releases calculated by sampling for a uniform distribution size bounds the release from a heterogeneous medium. (II-H-12.15)

EPA resolution of comment

EPA agrees that a uniform particle size is not appropriate. The CCA does not assume that waste degrades to a uniform particle size. Waste particle diameters in the spallings model were assumed to be distributed log-uniformly from $4x10^{-5}$ to 0.2 m (Docket: A-93-02, II-G-1, Appendix PAR, page PAR-115). Spallings releases are dominated by transport to the surface of solids of small particle size (see, for example Fig. 4.3.5 in Helton and Jow 1996, page 4-14,Docket A-93-02, II-G-07). Since use of a loguniform distribution biases parameter selection during LHS sampling to smaller (i.e., more conservative) values, releases will be higher with this parameter distribution. In addition, it was deduced from the findings of the Expert Elicitation Panel on waste particle diameters that the particle range was most probably between 1 mm and 10 cm which would reduce the spallings release (Memorandum entitled "Estimate WIPP Waste Particle Sizes Based on Expert Elicitation Results: Revision 1" from Yifeng Wang to Margaret S. Chu and Mel G. Marietta, Sandia National Laboratories, SNL WPO# 46936, June 27, 1997). The use of the mean particle size in determining the shear strength of the waste is a reasonable approach to characterizing the fact that the waste does not have a uniform particle size.

EEG's assessment of the EPA comment resolution

The EPA missed the point of this comment. The spallings model used for the CCA calculations did assume a uniform particle size. The uniform size was assumed to be uncertain and was therefore sampled from a range. However, the issue is no longer pertinent to the CCA because of the development of the newer spallings model.

537 [DOE argues that] a larger initial spall will be followed by less erosion than a smaller initial spall, resulting in the same final void ration. We find two errors in this argument: 1) The pressure difference between the waste repository and the hydrostatic pressure of the drilling mud can be over 6 MPa, three orders of magnitude above pressure differential need for explosive spall. 2) The second argument presupposes, without justification, that the erosion volume is larger than the initial spall volume and that the cavity caused by the initial spall will be partially filled by the erosion process. (II-H-12.16)

539 The spallings model does not include a sensitivity to scale leading the developers of the spallings model to state extrapolation of release volumes to WIPP, using the parameters evaluated using small scale laboratory models, has the potential for grossly under-predicting such releases. (II-H-12.18)

EPA resolution of comments 537 and 539

The CMPRP was not satisfied with several aspects of the spallings model as implemented in the CCA (see, for example, Docket: A-93-02, II-G-1, Volume XII, Appendix PEER, PEER 1, page 3-88 to 3-93). However, based on additional information subsequently developed by DOE and included in the Spallings Release Position Paper (Docket: A-93-02, II-G-23), the Panel concluded that the model was reasonable and probably conservative (Docket: A-93-02, II-G-22, page 12). EPA agrees with this position and believes this responds to EPA's initial concerns.

538 The model tests the erosion portion of the spallings phenomena for waste with no cohesive strength, but not the initial explosive phase, nor the effect of cohesion. (II-H-12.17)

EPA resolution of comment 538

EPA disagrees with the comment. The spallings model used in the CCA assumed that the cementation strength of the waste was 6,895 Pa or 1 psi (Docket: A-93-02, II-G-10, Appendix PAR, page PAR-190, ID #3245). Testing of surrogate waste mixtures as described in Spallings Release Position Paper (Docket: A-93-02, II-G-23, page 1-6) indicated that the strength of the waste was substantially higher than assumed in the CCA with the average tensile strength of saturated waste being 74,000 ± 40,000 Pa. Thus, the amount of spallings should be reduced as compared to that calculated in the CCA. (see response to comment 537 above.) EPA believes this increased waste strength would mitigate the impact of the "initial explosive phase" and that total releases would be well below the 0.5 to 4.0 m^3 range used in the PAVT calculations.

EEG's assessment of the EPA resolution of comments 537, 538, 539

EPA's assumption that the new spallings model is adequate to answer all spallings' concerns does not address EEGs' concerns. EEG believes that relying solely on the results from the new spallings model may be underestimating the importance of the issue. For example, the new spallings model cannot simulate all expected repository conditions. Locally varying waste permeability or different gas viscosities cause the code to produce erroneous results. It is therefore suggested that the EPA look more closely at the newer model before dissmissing any comment on spallings.

540 The "gas erosion" and the "stuck pipe", considered by the DOE in earlier performance assessments, have been excluded from the CCA spallings model. These two phenomena could cause releases that are over an order of magnitude larger than the largest releases calculated in the CCA. (II-H-12.19)

EPA Response to comment 540

EPA does not believe it is necessary to include gas erosion and stuck pipe processes in the CCA spallings model. Gas erosion and stuck pipe releases occur only if the waste permeability is less than $1x10^{-16}$ m^2 (Docket: A-93-02, II-G-1, Appendix CUTTINGS_S, page 37). In addition, the gas pressure in the intruded panel must exceed 8 MPa for gas erosion and 10 MPa for stuck pipe processes to occur. Based on earlier experimental work, DOE used a value for waste permeability of $1.7x^{-13}$ m^2 (see discussion in Section 1.3.2.7.4 of the TSD for '194.23 - Models and Computer Codes). More recently, DOE measured the permeability of surrogate waste mixtures based on current understanding of waste mixtures and degraded waste characteristics and determined the permeability of waste surrogates to be $2.1x10^{-15}$ to $5.3x10^{-15}$ m^2 on two samples (Docket: A-93-02, II-G-23, page 2-18). Based on the available waste permeability information, EPA concluded that the gas erosion and stuck pipe processes should not occur because permeabilities will be greater than the $1x10^{-16}$ m^2 threshold.

EEG assessment of EPA comment resolution

EEG still considers “stuck pipe” and “gas erosion” as potentially important processes in the calculation of spallings releases. See Section 2.4 of this report.

ISSUE 23.F: Three Dimensional Processes and Boundary Conditions

553 The EEG concludes that the use of a 2-D geometry in the BRAGFLO may introduce significant non-conservatism into the CCA calculations. The FEP S-1 needs to be reexamined with appropriate consideration of the impact of increased brine saturation on calculated estimates. (II-H-25.4)

EPA response to comment 53

EPA disagrees with the comment. The work that is most relevant to this concern is the FEP Screening Analysis titled S1: Verification of 2D-Radial Flaring Using 3D Geometry, WBS No. 1.1.6.3, SANDIA WIPP CENTRAL FILES-A: 1.2.07.3: PA:QA:TSK:S1, ERRATA - February 19, 1996 (SNL WPO #30840). In this work, a simplified version of the two dimensional CCA PA grid was tested against a corresponding three-dimensional (3-D) model. BRAGFLO was used in both two-dimensional (2-D) and 3-D simulations, and TOUGH28W was used to model the 3-D simulations only. Simulation results were compared for cases with an average repository gas generation rate, and a gas generation rate that was double the average. The results of the second case, in which the gas generation rate was doubled, indicates that a combination of pressure induced fracturing and the 1-degree dip cause flow paths which are different for the 2-D and 3-D grids. Once fracturing of the interbeds occurs, the 3-D model displays an immediate migration of gas primarily out of the west side of the repository into the anhydrite layers, accompanied by brine inflow to the repository. This phenomenon is not seen in the results from the 2-D model, in which the west side of the repository is a no flow boundary, which demonstrates that the 2-D and 3-D simulations show local variations. However, the results also show that the predictions of brine flow to the accessible environment are similar for both 2-D and 3-D grids. With respect to increased brine saturation, Figures 7 and 12 of the FEP Screening Analysis referenced above (WPO# 30840), shows the average gas saturations calculated with the 3-D simulations of TOUGH28 and both the 2-D and 3-D versions of BRAGFLO. Simulation results are compared for the base case and twice the base case generation rates, respectively. These curves indicate that gas saturations are higher in the 2-D simulations (WPO# 30840, page 27). Since brine and gas saturations are inversely related a similar trend would be observed for the brine saturations. In the Performance Assessment Verification Test (PAVT) , it was determined that the greatest potential releases could be attributed to those associated with spallings and direct brine releases. Furthermore, these releases are pressure controlled and will not occur if repository pressures are below 8 MPa. The fact that the 2-D model may overestimate gas saturation by underestimating brine saturations will lead to the prediction of higher gas pressures than those that would have been predicted with the 3-D configuration and this will result in more conservative estimates of releases. Based on this, EPA believes that the 2-D geometry used in the BRAGFLO CCA PA calculations is a reasonable simplification and that the predicted results are conservative.

EEG assessment of EPA resolution of comment 553

The EEG does not consider this issue to be resolved. See Section 2.10 of this report

Issue 23.W: CCA Parameters and PAVT Parameter Selection

550 The data and rationale for the sampled distribution of the waste-room residual-brine saturation is presented on pages PAR-27 through PAR-31. . .The non-conservative distribution of 0 to 0.560 reduces the estimated releases of direct brine release [sic].

Appropriate ranges for the waste room residual brine saturation are a constructed distribution using values from the eight unconsolidated materials; a uniform distribution from 0.0783 to 0.277, or a uniform distribution from 0 to 0.277. (II-H-25.1)

DOE Response to the Issue

845 The comment about the distribution of 0 to 0.560 for S [residual brine saturation of wr waste] being non-conservative is not correct because one should not be using a value just because it is more conservative. Instead, the use of a particular distribution or value should be based on how closely it represents the processes being modeled and how accurately it reflects realistic expectations of what will occur in the repository. The range of 0 to 0.560 was therefore chosen on the basis of being both reasonable and realistic. (II-H- 45.6)

EPA's Response to Comment 550 and 845

The residual brine saturation is that value at which no more flow will occur even with further decreases with capillary pressure. The range used for the CCA is based on literature values for unconsolidated materials. EPA agrees with DOE's comment, in that DOE has selected a reasonably representative range value for the wastes. This parameter will change with time, as the wastes gradually compacts, the porosity will become lower and the residual brine saturation will increase due to the increased capillary pressure of the smaller pores. Therefore, the low end on the distribution represents coarse material prior to waste compaction and the high end would be representative of fairly compacted waste. EPA's basic philosophy in dealing with such uncertain parameters has been to be reasonably sure that one or more of the following criteria are true : 1) that the values selected for a parameter in question leads to conservative results; 2) that the results are relatively insensitive to that parameter, or 3) that the selective range is representative of the actual parameter values. In the case of brine saturation, the complexity of the problem does not allow a predetermination to be made regarding whether a certain range or distribution is conservative. A further complicating factor is that the BRAGFLO computer code contains a wicking function that allows gas generation to occur even if the capillary pressures are low (Appendix BRAGFLO). Based on modeling experience EPA believes that residual brine saturation is insensitive and that the selected values does not impact the final results to a significant degree. EPA is confident that the range and distribution placed on the residual brine parameter are reasonably representative of the wastes and are adequate for use in the CCA PA calculations.

EEG assessment of EPA resolution of comment 550

Based on the information presented during the January session of the conceptual model peer review panel and to the particle size expert elicitation panel that some waste may be consolidated, the range of sampled residual brine saturation of the waste in the CCA calculations was appropriate.

551 Even though the parameter ranges recommended by Beauheim are more reasonable than the ones used in the CCA, the EEG disagrees with the recommended values for reservoir volume because the range includes the value derived from testing the ERDA-6 brine reservoir and initial pressure because of the use of data from twelve other brine encounters in the Salado. . . The recommended initial pressure range of 16.5 to 11.0 MPa gage is based on pressure measurements from thirteen Castile brine encounters. At WIPP-12 the measured pressure was 12.6 MPa gage. Therefore, the reservoir pressure should be a constant value of 12.6 MPa gage in the revised CCA calculations. (II-H-25.2)

EPA’s response to comment 551

No response given.

EEG assessment of EPA resolution of comment 551

See resolution to Issue 14.T on page 224.

552 If the samples distributions of parameters used in the CCA calculations are in error, but include the likely values of those parameters, should the CCA calculations be acceptable? The EEG position is that, under the these conditions, the CCA calculations should be repeated with the best estimate of the parameter distributions available. The use of a faulty distribution of one parameter biases the CCDF curves and confuses the assessment of uncertainty. The use of more than one faulty parameter set makes the assessment of uncertainties impossible because of the complex non-linear nature of the performance assessment models. (II-H-25.3)

EPA's general response to Issue 23.W and to comment 552

EPA performed a thorough review of the parameters and the parameter development process (see Section 12.4 on requirement §194.23 (c)(4) above in CARD 23 -- Models and Computer Codes; EPA Technical Support Document for § 194.23: Models and Computer Codes (Docket A-93-02, Item III-B-6); and EPA Technical Support Document for § 194.23: Parameter Justification Report (Docket A-93-02, Item III-B-14)). EPA reviewed parameter packages in general for approximately 1600 parameters used in the CCA Performance Assessment calculations. EPA further reviewed parameters record packages and documentation in detail for more than 400 parameters important to performance of the disposal system. Records reviewed include the Docket: A-93-02, II-G-1, Volume 1, Chapter 6, Tables 6-8 through 6-27, page 101 to page 166, A-93-02, II-G-1, Volume XI, all of Appendix PAR, WIPP parameter entry forms (464 Forms), Parameter Records Packages (PRP), Principal Investigator Records Packages (PIRP), Analysis Packages (AP), and Data Records Packages (DRP). The evaluation included a review of the expectations listed in the "Compliance Review Criteria" for §194.23(c)(4) above in Section 5.4.2. As a result of substantial information gathering at the Sandia Records

Center, EPA was able to uncover on its own substantial necessary documentation supporting most of the parameters used in the CCA PA. EPA first examined the sources of different parametric values used in the computer codes. EPA found that 416 (26.4%) of the 1571 parameters used in the CCA PA calculations are well-established constants found in general literature and general engineering knowledge. EPA discovered that DOE derived 887 (56.6%) of the parameters from experimental data, either from its own experiments or from journal articles. EPA also found that 89 (5.7%) are waste-related parameters derived from the waste inventory report (see docket: A-93-02, II-I-1, Volume III, Appendix BIR). EPA found that DOE selected the values of 149 (5.9%) parameters using professional judgment of its employees. Approximately 194 (12.3%) parameters were "legacy parameters" originally used in DOE's 1992 PA and again incorporated in the CCA PA (see Docket: A-93-02, II-I-31, Comment No. 11).

EPA selected 465 parameters on which to concentrate its analysis. EPA selected parameters to review based on the following criteria:

- parameters that appeared to be important to compliance or seemed to be poorly justified, such as material permeabilities and porosities, particle size, brine reservoir characteristics, pressures, solubilities of actinides, and waste inventory information,

- parameters that control various functions of the CCA PA computer codes that appeared to be important to compliance, such as permeability threshold, and dispersivity characteristics of the Culebra,

- other parameters EPA used to evaluate the overall quality of SNL's documentation traceability, such as reference constants and general reference values.

The purpose of the parameter review was to verify that DOE's documentation includes adequate information to fulfill the compliance review criteria of section 12.2, for §194.23(c)(4) of this CARD. For greater detail about EPA's examination of the specific parameters in each category, see EPA Technical Support Document for Section 194.23: Parameter Justification Report (Docket A-93-02, Item III-B-14).

EPA strongly believes that EPA-mandated Performance Assessment Verification Test was done with the best estimate of the parameter distributions available. EPA did an exhaustive review of the parameters used in the CCA PA and altered those needed and required DOE to repeat the calculation with the necessary changes. See A-93-02, III-B-5, II-G-26 and II-G-28 for documentation of the changed parameters and their impact on potential releases.

EEG assessment of EPA resolution of comment 552

Though the EPA did a thorough job in evaluating the parameters for the PAVT, the EEG believes that the performance assessment evaluation is still incomplete. For example, the EPA studied the evidence carefully when considering the Castile Brine Reservoir parameters and selected relevant values to assign to the parameter. Yet, the solubility of certain actinides in Salado and Castile brines or the partition coefficient of actinides for sorption onto the Culebra Dolomite and the probability of brine reservoir encounter were inadequately addressed. These few examples play an important role in compliance, as studied by the EEG in sensitivity analyses (Section 2.2 of this report). The synergetic effect off all parameters is unknown, and it is important to characterize each parameter carefully. The EEG believes that this has not been done, and perhaps a new performance assessment should be conducted with parameter values that are more easily justified through experimentation.

554 The sampled parameter for the probability of microbial gas generation determines whether cellulose and plastics and rubber will be degraded by microbial action after

closure of the repository. . . It is the opinion of EEG that the numerical value of this parameter constitutes expert judgment. Given the importance of this parameter to the estimates of radionuclide release, this parameter should be demonstrated to be either solidly based on scientific evidence or be conservative. The justification for this parameter presented in support of the CCA does neither of these. (II-H-25.5)

DOE response (II-H-45)

The interaction of gas generation with other processes in the repository is complex. Because of this, an *a priori* determination of a meaningful, conservative selection from the possible processes of gas generation is difficult. The suggestion of the EEG that microbial degradation should always be specified, i.e., a 100% probability, is not necessarily conservative since this would tend to reduce brine inflow. Therefore, to be consistent with the treatment of uncertainty throughout the performance assessment, the DOE assigned probabilities to gas generation processes to ensure that assessment results reflect the uncertainty associated with the occurrence and extent of these processes, i.e., both possible outcomes be sampled.

The conceptual model for gas generation in the WIPP repository includes two dominant generation processes: metal corrosion and microbial degradation of organic material. The probabilities of occurrence of these processes were established through a procedure that included careful review of uncertainty suggested by experiments conducted specifically for the WIPP, literature review, and consideration of local scale processes in the disposal room. Given the presence of brine, it is reasonable to assign a 100% probability to metal corrosion. However, there are considerable uncertainties associated with the occurrence of significant microbial populations. These are:

(1) Whether micro-organisms present in the waste are capable of carrying out the potentially significant processes that generate gas identified by Brush[6].

(2) Whether these microbes will survive for a significant fraction of the 10,000 year period of performance of the repository.

(3) Whether sufficient electron acceptors (oxidants) will be available to any microbes that survive.

(4) Whether enough nutrients, especially N and P, will be available.

Electron acceptors and nutrients will be present in the repository (see Appendix BIR7). Therefore, points (3) and (4) relate to the uncertainty as to whether these materials will be physically and chemically available to any microbes that survive. Brush[8] discussed these issues in more detail.

In addition to uncertainty over the possibility of microbial activity, there is also uncertainty over the amounts and types of biodegradable waste. It is reasonable to assume that readily biodegradable material such as cellulosics will be consumed if microbes are active. However, plastics and rubber are much less biodegradable than cellulosics and may not contribute to the gas generation process. Two factors may potentially increase the biodegradability of those materials: (1) long time scale; (2) co-metabolism. Over a time scale of 10,000 years, the chemical properties of plastics and rubbers may change, possibly resulting in enhanced biodegradability. Furthermore, micro-organisms may co-metabolize plastics and rubbers with cellulosics and other more biodegradable organic compounds. All of these uncertainties precluded the use of experimental and/or modeling studies to quantify the probability of significant microbial gas generation in WIPP disposal rooms and the probability of significant microbial degradation of plastics and rubbers for the performance assessment calculations to support the CCA.

To incorporate the uncertainty about the dominant processes of gas generation, the DOE assigned a value of 50% to the probability of significant microbial gas generation and 50% to the probability of significant microbial degradation of plastics and rubbers in the case of significant microbial gas generation. In other words, steel corrosion alone occurs in 50% of LHS sample vectors, steel corrosion and microbial degradation of cellulosics occurs in 25% of LHS sample vectors, and steel corrosion and microbial degradation of cellulosics, plastics, and rubbers occur in 25% of LHS vectors. This is consistent with the treatment of uncertainty throughout the PA calculations (see Appendix PAR, page PAR-6, Delta Distribution). As the EEG requests, it is also based on scientific evidence as to the likely gas generation processes and ensures that all the possible complex interactions between gas generation and other processes are accounted for.

The EEG also states that the gas generation probabilities used should be peer reviewed. In fact the Conceptual Model Peer Review Panel have done this (see Appendix PEER, Section 1). With regard to the gas generation model probabilities, the Panel stated (p. 3-144 to 145):

> "Regarding microbially induced gas generation, the model assumes that the probability of degradation of cellulose and plastics/rubber will be 50% and that in the event that biodegradation occurs there is a 50% probability that plastics and rubbers will also be degraded." [Illustration callout and illustration omitted in this quote]

> "This assumption is based on major uncertainties that are described in Section 3.21.2.4 below, and represents a judgement. For performance assessment purposes, this assumption will result in less gas generation than if one were to assume total consumption of all the organic material. There is apparently no scientific evidence that plastics/rubbers degradation will occur at all with certainty,

based on contemporary experience. The possibility that products from microbial degradation of cellulose, and perhaps radiolysis by alpha irradiation, could combine to break down the relatively stable plastics polymers to more consumable fragments suggests the probability should be non-zero. It is difficult to argue for a value higher or more precise than 50%, unless there were more robust long-term data, or experience with plastics degradation in, for example, landfills. Therefore, for performance assessment purposes, the assumption regarding plastics/rubbers appears to be adequate.

With regard to the degradation of cellulose, the long list of uncertainties identified in Section 3.21.2.4 below suggests that less than full probability of significant microbial degradation of this more readily consumable material is a reasonably valid assumption. Also, it does not appear scientifically valid to assume that either all or none of the cellulose will be degraded in light of the significant uncertainties that microbial populations would remain viable to the extent of complete cellulose degradation. DOE is not seeking a worst case in performance assessment. Therefore the 50% probability is a reasonable assumption for modeling purposes."

The DOE believes this excerpt shows that the Conceptual Model Peer Review Panel fully understands the goals of performance assessment in general, the purpose of model and parameter selection, and in particular the basis and reasonableness of the DOE gas generation model.

EPA's response to comment 554

EPA has examined information to support these parameters. See EPA Parameter Justification Report (Docket A-93-02, Item III-B-14), Section 5.25, for detailed discussion of the PU, PROPMIC parameter.

Section 5.33, for detailed discussion of the AM, PROPMIC parameter.

EEG assessment of EPA resolution of comment 552

It appears from the response that EPA did not understand the question. The EPA response in Section 5.25 and Section 5.33 (U.S. EPA, 1997m) addresses concerns of Plutonium and Americium sorption onto microbial colloids and humid colloids.

The sampled parameter for the probability of microbial gas generation determines whether cellulose and plastics and rubber will be degraded by microbial action after closure of the repository. No degradation of cellulose or plastics occurs in the calculations with a 50% probability. Only cellulose degrades in 25% of the sampled vectors. Cellulose, plastics, and rubber degrade with a probability of 25%. The preliminary sensitivity analysis report (Helton, 1996) lists this parameter as the largest influence on the variation of total calculated release from the WIPP repository.

The documentation supporting this parameter does not contain any numerical justification for the probabilities assigned to this parameter. All of the hand calculations performed to calculate the gas generation parameters are included as attachments to the memo of Wang and Brush (1996). Calculations for the degradation probabilities are absent from these attachments. It is the opinion of EEG that the numerical value of this parameter constitutes expert judgment. Given the importance of this parameter to the estimates of radionuclide release, this parameter should be demonstrated to be either solidly based on scientific evidence or to be conservative. The justification for this parameter presented in support of the CCA does neither of these.

The numerical values of the degradation probability parameter should undergo peer review consistent with expert judgment. Otherwise, the parameter should be conservatively set to always specifying microbial degradation of cellulose, plastics, and rubber.

EEG assessment of DOE's response

The parameter used to set the probability of microbial degradation in the CCA calculations is not derived analytically but instead was a result of interpretations that constitute expert judgment. The EEG suggested that the probability of microbial degradation should undergo peer review as parameter obtained using expert judgment. It was suggested that without this peer review the microbial degradation parameter should be set to always specifying microbial degradation of cellulose, plastics, and rubber. The EEG has been convinced by DOE's arguments that setting the parameter to always specifying microbial degradation of cellulose, plastics, and rubber is not appropriate. The central point remains that the probabilities used in the CCA calculations are a result of expert judgment. As such the parameter is required to be peer reviewed using the procedure outlined in 40 CFR Part 194.26. The conceptual model peer review does not meet the requirements outlined in the section.

557 If a single value for the consolidated waste permeability is to be used for direct brine release, then it should be 2.4×10^{-13} m^2 and not 1.7×10^{-13} m^2 . (II-H-25.8)

DOE's response to comment 557

The [waste permeability] value of 2.4×10^{-13} m^2 is both reasonable and is as technically correct as the 1.7×10^{-13} m^2 value. There has been no technical reason offered which would justify using the higher value instead. (II-H-45.5)

EPA's response to comment 557

EPA has examined information to support this parameter. EPA believes that a single value instead of a probability distribution is justified for permeability. See EPATechnical Support Document for Section 194.23: Parameter Justification Report (Docket A-93-02, Item III-B-14), Section 5.19, for detailed discussion of the BLOWOUT, APORO parameter.

EEG assessment of EPA resolution of comment 557

Refer to EEG Chapter 2.4 for full explanation of EEG's concerns and responses.

Section 194.27 (CARD 27) Peer Review

ISSUE 27.A: EPA should look carefully at Peer Review conclusions

2 Our impression is that certain panels have performed a thorough and credible review, while others have not. Our recommendation to the EPA is to review the bases of findings of the panels and subject them to your own critical review by the EPA staff, contractors, or formally assembled peer review groups. (522) (II-H-12.1)

EPA's response to Issue A

EPA's audit of DOE's records did not result in any findings that substantially compromised the credibility of the process used to implement the peer reviews required by Section 194.22(b) or Section 194.27(a) (see "EPA Compliance Review" under 194.27(b) above). As stated in EPA's response to comments received on the proposed compliance criteria, "The Agency does not intend for peer review of DOE's activities to supplant or replace the Agency's review of compliance applications. . . Regardless of the recommendations or judgments made by the peer review groups, all decisions on the adequacy of the compliance application will be EPA's and EPA's alone" (Response to Comments Document for 40 CFR Part 194, pp.9-6 to 9-7). In other words, EPA recognizes that peer review contributes to but does not supplant the Agency's independent review. EPA therefore considered peer review panels' findings in technical areas in conjunction with other information relevant to compliance. EPA's consideration of the scope and findings of the required peer reviews may be found in **CARD 22 – Quality Assurance, CARD 23 -- Models and Computer Codes, CARD 24 -- Waste Characterization, and CARD 44 -- Engineered Barriers**.

EEG assessment to EPA resolution of comment 2

It appears that discussions on several issues dealt by peer review groups may have been made without EPA's own analysis. An example is the new spallings code. The peer review accepted the conceptual model, without an actual testing of the code. The EEG found that after conducting a thorough sensitivity analysis with the codes, variations in several parameters may lead to conclude that the CCA spalled volumes are not conservative. If the EPA had conducted their own analysis, they too would have reached to the same conclusion. The same can be seen with the issue of actinide solubility or actinide partition coefficient (K_d).

Section 194.32 (CARD 32) Scope of Performance Assessment

ISSUE 32.A: The CCA does not adequately address the effect of fluid injection on the repository

12 The DOE has chosen "soon after disposal" to mean 50 years in the context of the fluid injection scenario. However, in the 1991 DOE elicitation of expert opinion on future activities in the vicinity of WIPP, one of the four teams addressed fluid injection and assigned probabilities of waste brine disposal associated with other industrial activities for

the full 10,000 years. Further, the probability of a large number of such injection wells, within the site was predicted to increase with time. (526) (II-H-12.5).

13 The discussion of fluid injection in Appendix SCR of the CCA is incomplete and largely incorrect. For example, Appendix SCR mentions gas injection for natural gas storage in the Morrow Formation but fails to mention natural gas storage in the Salado Formation. It is argued that the differences between the geology at WIPP and the Vacuum Field and Rhodes-Yates Field provide for more potential thief zones below the WIPP horizon in the event of water escaping the injection zone. However, field evidence strongly suggests that brine injection into the Bell Canyon below the WIPP horizon appears to be leaking into the Culebra aquifer above the WIPP horizon. The CCA provides no experimental evidence such as the measurement of water quantities in the anhydrite beds of the Salado Formation to support the CCA speculation. (527)(II-H-12.6)

14 The claim that there will no waterflooding on the scale of Rhodes-Yates is also undermined by field evidence. (528)(II-H-12.7)

15 While the Delaware sands, including those around the WIPP produce large volumes of water, they are nonetheless, technically and economically amenable to waterflooding as well as CO2 flooding. (529)(II-H-12.8).

16 The CCA-SCR notes that state regulations do not allow injection pressures to exceed the rock fracture pressure. However, that portion of the regulation applies to the target injection zone and not any overlying formations. The producing reservoirs near WIPP are greater than 7,000 feet. One consequence of greater vertical distance is that the surface injection pressure is automatically approved for 1,400 psi or 0.2 psi per foot. This corresponds to 2,400 psi at the WIPP horizon which is well in excess of the fracture pressure of the anhydrite beds in the Salado Formation.(531)(II-H-12.10).

17 Stoelzel and O'Brien consider only salt water disposal and assume an injection depth of 260 feet, a surface injection pressure of 850 psi, and a pressure at the WIPP horizon of 1,900 psi. However, pilot water flooding operations near WIPP are underway for reservoirs at 7,000 feet depth and have been approved to inject at a surface pressure of 1,400 psi, which in the event of communication, would exert a pressure of 2,400 psi at the WIPP horizon. Hence, the anhydrite beds in the Salado Formation would fracture, as successfully argued by Hartman and brine would migrate for miles in the inadvertent waterflooding hydro fracture scenario. (532)(II-H-12.11).

EPA's comment to Issue 32.A

DOE evaluated fluid injection in connection with the scope of the performance assessment but rejected the scenario on the grounds of low consequences. EPA evaluated DOE's Hartman Scenario and also performed an independent fluid injection analysis; see EPA Technical Support Document for 194.32: Fluid InjectionAnalysis (EPA 1997b). The results of these studies show that effective permeability in marker beds is probably lower than that used in the PA, and that other factors (such as injection rate, injection interval, etc.) also play a very important role in fluid injection. EPA agrees that under very unrealistic conditions, modeling can show fluid movement toward the WIPP under an injection scenario. These conditions include those modeled by Bredehoeft, such as steady state flow, two well scenarios, and pulsing flow. However, when modeling assumes more realistic but still conservative conditions, fluid movement sufficient to impact disposal performance of the WIPP does not occur.

In addition, EPA believes that geologic and hydrogeologic conditions in the Hartman area are different than in the WIPP area, which also precludes one-to-one comparison of conditions at the WIPP and at the Bates lease. For example, the Castile Formation is not present in the Bates area, but over 1,000 feet of Castile is present in the WIPP area. Also, the present oil well completion practices in the Delaware Basin are substantially improved. Injection rate, pressure, target and fluid volume related regulations are different and are closely monitored by the state agencies. EPA concludes that the model representation in DOE studies, including two-dimensional analysis, appears to be appropriate for the intended use, because the model uses radial flaring in the z direction to capture compatible volume in the 360 o flow to compensate for 3D simulation.

EPA also requested (see Docket A-93-02, Item II-I-17) that DOE consider different factors in its fluid injection modeling (Stoelzel and Swift, 1997). Refer to the discussion in this CARD under 194.32(c). EPA concluded that DOE's initial modeling studies (Stoelzel and O'Brien, 1996) and supplemental modeling studies (Stoelzel and Swift, 1997 and Docket A-93- 02, Item II-I-36), together with EPA's own fluid injection analysis (EPA 1997b) all indicate that DOE's screening of fluid injection from consideration in PA is appropriate. EPA also notes that DOE considered waterflooding for the undisturbed (historical, ongoing, and near future time frame) and screened it from consideration based upon consequence. In so doing, DOE is not required by the Compliance Criteria to evaluate this FEP for the long-term future.

EEG Assessment to EPA Resolution of Issue 32.A

As discussed in Secion of 2.6 of this report, the EEG disagrees with the EPA on this issue.

ISSUE 32.C: The CCA does not adequately consider solution mining of potash

4 The CCA (Appendix MASS, p. 87) claims that the DOE is not aware of any ongoing solution mining in the Delaware Basin. However, that activity has been ongoing for

several decades in southeast New Mexico, including the Delaware Basin, to provide brine for oil field drilling operations. Furthermore, state records show fluid injection for solution mining of halite is expanding into areas closer to the WIPP to meet the needs of drilling activities in that area. (533)(II-H-12.12)

8 The CCA inappropriately eliminates solution mining for potash. DOE relies on current regulations which do not fully cover all scenarios, nor do they prevent solution mining for potash. (751) (II-H-32.12)

DOE's response to Issue 32.C

It is unlikely that potash mine operators in the vicinity of the WIPP will elect to use solution mining in the future, even once Sylvite deposits are fully mined out by conventional excavation methods, because conditions are economically unfavorable, as noted by Heyn (1997), a potash mine operator within the Delaware Basin. Points raised by Heyn (1997) are summarized below: (1) Solution mining requires heat to increase the ambient temperature of the injected water in order to increase the dissolved salt capacity of the brine. This is usually accomplished by taking advantage of geothermal heat found in deep wells or mines. Most solution mines are at depths in excess of 3,000 feet (910 meters). The potash ore bodies in the vicinity of the WIPP are less than 1,740 feet (530 meters) below the surface. Also, the cost of evaporation equipment to recover the potassium salts may be prohibitive. (2) Solution mining of the Sylvite ore bed in the vicinity of the WIPP would result in excessive solution of unwanted minerals and clays because the ore zone is too thin. Solution mining usually requires an ore bed thickness in excess of 10 feet. (3) Unavailability and cost of fresh water in the area would impede implementation of solution mining. (4) Potash ore reserves in the vicinity of the WIPP are too low in potash grade and the life expectancy of the mines is too low to justify the cost of constructing a solution mining refinery. Thus, it is likely that the potash bearing ore zones in the vicinity of the WIPP will continue to be extracted using conventional room and pillar methods, rather than solution mining. (724)(II-H-24.19)

EPA's response to Issue 32.C

EPA agrees that the CCA did not appropriately treat solution mining of potash; however, DOE provided supplemental information concerning solution mining in response to public comments e.g., DOE, 1997i, 1997m, and Docket A-93-02, Items II-H-44 and II-H-45). DOE indicated that the target potash intervals for conventional room and pillar mining are Zones 4 and 10, which would also be the target horizons for solution mining. DOE concluded that the effects of solution mining relative to changes in overlying Culebra hydraulic conductivity are included in the modeled effects of room and pillar mining. The increase in hydraulic conductivity is related to the reduction in confining stress. Unless the mean confining stress is reduced to zero, the increase in hydraulic conductivity will be considerably less than what DOE has considered in PA. However, DOE indicated in supplemental information that solution mining is not likely in the vicinity of WIPP because fresh water for mining is limited and the overall procedure is cost prohibitive. Also, langbeinite, which is the primary target of extraction, is not readily soluble in water.

EPA noted that a permit is being sought for a pilot solution mining venture in the Carlsbad area. However, it is not possible to accurately predict the future possible minable zones if mining techniques are refined. Solution mining is presently not being done and may not take place in the future, and solution mining would likely include those horizons already included in the room and pillar mining modeling assumptions. With the supplemental information, EPA concludes that DOE has sufficiently addressed the potential effects of potash solution mining and that they were addressed within the scope of the PA.

EEG assessment of EPA response to Issue 32.C

EEG's responses to EPA are:

- EPA's conclusion that potash solution mining is not likely at WIPP relies on solicited comments that are factually incorrect and inconsistent with the published scientific literature.

- DOE and EPA maintain that excavation mining captures the effects of solution mining on the hydraulic conductivity of the overlying aquifers. However, based on the scientific literature, the prediction of subsidence above solution mines can be much more complex than the prediction of subsidence due to excavation mining. This issue needs to be reevaluated for the final rule for WIPP.

- Potash is a resource used for the production of food, therefore it appears to be incorrect to calculate a probability of mining based on past potash production which was inherently dependent on past mineral economics and the availability of high grade ore. It also seems reasonable to assume that low grade potash ores will eventually be mined to meet world demand.

ISSUE 32.D Potash reserve assumptions are contradictory and/or inadequate

8 The CCA claims credit for addressing the issue of potash mining. However, the CCA underestimates the areal extent of potash reserves and the potential impact of the excavation mining of potash within the site and on adjacent federal and state properties. The use of only existing releases adjacent to the site does not account for the currently economical potash reserves. . . Further, the Department of Interior notes that potash ore

has been and can be economically mined at ore concentrations less than current lease grade. (560) (II-H-25.11)

EPA's response to Issue 32.D

EPA concurs that the DOE and BLM minable footprints do not coincide. Relative to potash, the CCA indicated that only the 4th and 10th horizons are economic reserves, although remaining ore zones are considered resources that would be mined with advances in thin-seam extraction technologies. However, the minable footprint presented in the CCA on Figure 2-38 does not entirely match or coincide with the locations or information presented by Griswold in NMBMMR 1995. DOE provided supplemental information concerning the minable potash footprints, in response to stakeholder questions (Docket A-93-02, Item II-H-45). Although the minable footprints identified by DOE and Department of Interior differ, DOE concluded that this is due to the difference between the definition of "resources" and "reserves." (Reserves are hose resources that are currently economically recoverable with currently available technology, and resources are mineral deposits that are not currently economical or have not been discovered.) That is, DOE contended that their estimates were based on actual minable reserves, which are less pervasive than resources. However, DOE also contended that this approach is consistent with the intent of Section 194.32(b), which states that DOE must consider resources similar in quality and type to those currently extracted.

EEG assessment of EPA response to Issue 32.D

The EEG has conducted a sensitivity analysis pertaining to the extent of potash reserves within the controlled area. The conclusion is that with current models and the implementation of mining in those models (increase in effective transmissivity of the Culebra), the scenario has little effect. However, simply increasing the transmissivity within the Culebra does not account for all processes involved in subsidence due to mining, and other parameters, such as fracture width, or porosity may be significantly changed. Therefore, the EEG concludes that a more accurate portrayal of mining should be included in the performance assessment, including extent and consequence.

ISSUE 32.I: Justification of FEPs screening

3 Operations involving the screening and other processing of FEPs are inadequately documented. 25% of the original FEPs list was eliminated with no documentation of the process; 70% of the remaining FEPs have essentially no more documentation than what appears in the CCA. The documentation for the other 30% also appears to be incomplete. The rationale for excluding many of the FEPs from the PA is not documented in the CCA. (559) (II-H-25.10)

EPA's response to Issue 32.I

In general, EPA found DOE's screening analyses and justifications for inclusion or exclusion of FEPs to be adequate. However, EPA determined that additional information or justification was necessary regarding certain FEP issues (e.g., dissolution, brine mining, solution mining, and fluid injection). Public comments also identified similar deficiencies in the screening analyses for some FEPs in the CCA. DOE provided supplemental information addressing EPA's questions and public comments (Docket A-93-02, Items: II-I-24, II-I-31, II-I-34, II-I-36, II-I-37). EPA reviewed the information and concluded that DOE's responses have adequately addressed all its concerns regarding FEPs and scenarios.

EEG assessment of EPA response to Issue 32.I

The EEG does not agree that the screening of FEPs in the CCA were adequate. The fluid injection scenario (Section 2.6 of this report), for example, addresses several concerns of the inadequacy by the DOE and EPA in their analysis. Also, arguments can be made on the Air Drilling Scenario (Section 2.5) and issues surrounding production well ERDA-9 (Section 2.14).

Section 194.33 (CARD 33) Consideration of drilling events in performance assessment

ISSUE 33.B: The Performance should incorporate lower plug permeabilities

555. Borehole lifetime should be a sampled parameter in the CCA calculations or else the DOE should provide demonstration that variations in borehole lifetime do not effect [sic] the release estimates. (555)(II-H-25.6)

EPA response to Issue 33.B:

EPA reviewed natural borehole degradation processes and the subsequent effect of these processes on borehole permeability. Based on available information (e.g., WPO# 41131 and Appendix PAR, p. 192), EPA found that a constant value of permeability 10^{-14} m^2 throughout the regulatory period would not be conservative because of pressure buildup in the repository. The Agency believes that, primarily due to the solidification of drilling muds within the borehole in time, variations in the permeability of borehole plugs will occur and that a lower value of permeability would be more realistic than the constant and relatively high permeability value that DOE used.

EPA agrees that DOE gave little credit to factors that could sustain or enhance the potential effectiveness of plugs. Although DOE provided a combination of site-specific and theoretical justifications in support of plug parameter assignments, the assumed value of the plug permeabilities is subject to uncertainty and EPA determined that a modification of DOE borehole plug permeability values was necessary. EPA required that EPA-mandated PA simulations be conducted using lower permeability values (parameters used in model- CONC_PLG maximum of 10^{-19} m^2, BH_SAND maximum of 5 x 10^{-17} m^2) to account for possible cases in which complete degradation does not occur throughout a well, or natural materials and mud provide additional layers with sealing properties.

EEG assessment of EPA resolution of Issue 33.B

The EEG suggested the borehole plug lifetime should be a sampled parameter based on two observations. 1) It is likely that the performance assessment calculations are sensitive to the assumed borehole plug lifetime. 2) Borehole plug lifetime is an uncertain parameter. The use of a constant value for borehole plug lifetime in all the calculations is inconsistent with DOE's guidelines for sampled parameters. Contrary to the assertion in the DOE response (II-H-46), the EEG did not argue that the estimate of 200 years is unreasonable.

The DOE (II-H-45) claims that borehole plug lifetime uncertainty is accounted for by assuming that two percent of the plugs are continuous (long-lived) and hence do not degrade (II-H-46). This claim is wrong.

The EEG recognizes that sampling borehole plug lifetimes would be impractical using the present performance assessment design. The DOE should investigate the influence of borehole plug lifetimes on repository conditions and assess the potential impact on CCDF calculations.

The EPA mandated verification test used a range of permeabilities of degraded boreholes that extended lower than the range used in the CCA calculations. The lowest permeability effectively limits flow through the borehole. The effect may have similar consequences to the effect on the repository conditions of long lived borehole plugs. Thus, the EPA mandated verification test may, in conjunction with the CCA calculations, provide a bound on the influence of variable borehole lifetimes. This, however, is speculation and needs to be confirmed.

Issue 33.D: The estimated probability of intersecting a pressurized brine reservoir is adequately/inadequately justified, and E1 intrusions will not necessarily affect disposal system performance.

219. EEG finds no justification for assuming only eight percent probability of intercepting a pressurized brine reservoir in the Castile Formation, 800 feet below the repository. (219)(A-50 [II-H-12])

EPA response to Issue 33.D:

EPA found that DOE's representation of brine pocket occurrence probability in the CCA was not consistent with available information. EPA requested that the brine pocket probability be modified to range from 1 percent to 60 percent, and that it must be a sampled value rather than a fixed value of 8 percent. These values were used in the PA verification test (PAVT). Results of the PAVT indicated that the modified Castile Brine Pocket parameters increased releases (DOE 1997a, 1997b). However, the resulting PAVT CCDF curves, while closer to the EPA limit than PA CCDF curves, are still well below the EPA limits. EPA agrees that the E1 scenario does not always enhance radioactive releases in all instances. Refer to **CARD 14-- Content of Compliance Application** for further discussion of brine pocket probability.

EEG assessment of EPA resolution to Issue 33.D

There is poor justification for the 1% lower end of the EPA range for the probability of encountering a pressurized brine pocket. The 60% upper end is based on an electromagnetic survey of the WIPP site (US. DOE, 1996c, 2.2.1.2.2) that indicates brine is likely under about 60% of the repository. Most importantly, the probability of hitting brine under WIPP should be based on WIPP, not the entire Delaware basin. The WIPP-12 brine reservoir is of sufficient size to protrude under the repository. The existence of boreholes around WIPP-12 that have not encountered brine in the Castile constrain the WIPP-12 reservoir so much that it is almost certain that the reservoir extends under the repository (II-H-25). The brine indicated by the electromagnetic survey must be part of the WIPP-12 reservoir. The probability of encountering brine should be modeled as 60%. The PAVT thus underrepresents the probability of encountering a brine reservoir.

Section 194.41 (CARD 41) Active Institutional Controls

ISSUE 41.B: DOE should provide specific commitments preventing human intrusion for 100 years

1 EEG recommends that EPA should require DOE to provide specific commitments on how they will prevent human intrusion for the first 100 years. As part of building a credible argument, the CCA should also take into account the pessimism of its own expert elicitation on the limited effectiveness of active institutional controls. (562) (II-H-25.13)

EPA response to Issue 41.B:

Upon preliminary review of the CCA, EPA requested that DOE provide specific commitments concerning AICs for the WIPP site, including fencing, signs, and site patrols (Docket A-93-02, Item II-I-01). DOE provided the requested information (Docket A-93-02, Item II-I-07, Enclosure 1c). DOE also described legal prohibitions on resource extraction and other activities at the WIPP site that function as AICs, such as the erection and testing of passive institutional controls and the implementation of the site monitoring plan.

DOE did not conduct an expert elicitation for the purpose of determining how long the proposed AICs specifically are expected to be effective. As EEG noted, an expert elicitation conducted prior to the promulgation of the final Compliance Criteria resulted in predictions of AICs' effectiveness generally (see A-93-20, Item II-H-25). However, DOE did not rely on these predictions in proposing that AICs will be completely effective for 100 years. EPA believes that it is fully within DOE's capacity to maintain the proposed controls for 100 years after disposal, is discussed under EPA Compliance Review for Section 194.41(a) above.

EEG assessment of EPA resolution to Issue 41.B

Title 40 CFR 191.14 (a) requires maintenance of active institutional controls for as long a period of time as is practicable after disposal, but the credit in performance assessment may not be taken for more than 100 years. The DOE has proposed controls for 100 years and has assumed no drilling in the repository for that period. The EEG agrees with the EPA's finding for this requirement, but recommends that if in the final rule EPA finds WIPP to be in compliance with the standards and proposes to grant certification, oversight by the federal (other than DOE) and state authorities should be required to ensure vigorous implementation of the active institutional control.

Section 194.43 (CARD 43) Passive Institutional Controls

ISSUE 43.B: DOE's proposal for PICs credit is or is not acceptable

5 Based on DOE's experience with institutional controls in the recent past, a claim of 99% credit for passive institutional controls for 700 years does not appear justifiable. (561) (II-H-25.12)

EPA response to Issue 43.B

EPA proposes to deny DOE's application for PICs credit for two reasons. First, DOE did not employ expert judgment to derive the credit. EPA stated in the preamble to 40 CFR Part 194 that "the degree to which PICs might reduce the future drilling rate can be reliably determined only through expert judgment" (61 FR 5232). Instead, DOE developed a proposal and submitted it to a peer review panel of three experts. EPA does not view peer review as equivalent to expert judgment. The Agency laid out explicit requirements for the conduct of expert judgment in Section 194.26.

Second, EPA found that DOE's analysis does not account persuasively for the uncertainty associated with the forecasting the effectiveness of PICs. EPA does not concur with the conclusion of the PICs peer review panel that DOE's proposed credit is reasonable. Among other issues, EPA considers DOE's assertion that every aspect of the PICs design is virtually certain to endure and be understood for the proposed period to be contrary to EPA's specification in Section 194.43(c) that "[i]n no case. . . shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely" (61 FR 5243). This topic is discussed in greater detail in EPA Compliance Review for Section 194.43(c).

EEG assessment of EPA resolution of Issue 43.B

The EEG agrees with this determination of denying credit for PICs for reasons stated by the EPA in U.S. EPA (1997c), as well as for reasons that EEG has previously submitted to the EPA (see Appendix 8.2-Passive Institutional Controls).

Section 194.44 (CARD 44) Engineered Barriers

ISSUE 44.A: Borehole plugs, shaft seals, panel closure, and backfill should/should not be considered engineered barriers.

5 Shaft seals are at best an attempt to undo the damage done to the natural environment when the shafts were excavated, and therefore cannot be an engineered barrier as distinct and complementary to the natural barriers. (545) (II-H-12.24)

6 Like the shaft seals, panel closure systems (separation of waste panels by engineered structures) cannot be considered to be engineered barriers because they too can at best be imperfect attempts to restore the original natural system. Panel seal is not included in the examples of engineered barrier in EPA definition (Section 191.12). (546) (II-H-12.25)

7 The fact remains that the purpose of including MgO in the WIPP repository is to control the chemical conditions in the WIPP repository to allow assumption of lower actinide solubility values. It may therefore satisfy a need for the Containment Requirement of the Standards, but does not provide complementary added assurance visualized by the Assurance Requirements (40 CFR 191.14). (547) (II-H-12.26)

8 Since the stated requirements for plugging the boreholes (Section 3.3.4 and Figure 3-10 of the CCA) are much less stringent than the shaft seals, the borehole plugs have a lesser claim as engineered barriers. The NRC specifically excludes borehole seals as part of an engineered barrier system. Hence, the borehole plugs should not be considered to be an engineered barrier. (548) (II-H-12.27)

EPA response to Issue 44.A

Section 194.14(b)(1) required DOE to include in the description of the disposal system information about engineered barriers, i.e., "any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment," as defined at Section 191.12. The CCA treated panel seals, shaft seals, and borehole plugs as features of the disposal system design, and EPA evaluated them in that context. For a discussion of these features, see Section 194.14(b)(1) and Response to Comments in **CARD 14 – Content of Compliance Certification Application.**

For the purpose of complying with the assurance requirements at Section 194.44, DOE proposed to implement one engineered barrier -- magnesium oxide (MgO) backfill. EPA believes that DOE adequately demonstrated in the CCA and supplementary information that MgO will serve to prevent or substantially delay movement of water or radionuclides toward the accessible environment. For more discussion of the effectiveness of MgO backfill, see Section 194.44(a) above in this CARD, as well as Response to Issue C below.

EEG assessment to EPA resolution to Issue 44.A

Title 40 CFR 191.14 (d) requires use of both engineered and natural barriers in the repository design. The CCA proposed a chemically-buffering magnesium oxide backfill as the only engineered barrier, and the EPA has accepted in the proposed rule the DOE (U.S. DOE, 1996c) proposal to satisfy this assurance requirement. The EEG view is that while there are still some questions about the efficacy of the chemical buffer aspect of the magnesium oxide (MgO) backfill (see Appendix 8.4, section 2.3 of this report), this engineered feature has been selected primarily to enable DOE to use numerical values of certain parameters in the containment requirement calculations. The MgO backfill may not therefore be considered to satisfy this assurance requirement in a strict sense of the philosophy of these requirements. Incorporation of backfill in the WIPP design is nevertheless a good idea and the EEG has been recommending a salt/clay mixture as backfill for years. A pure MgO backfill does not have the benefit of the chemical retardation of radionuclides that clays afford, but may help keep the repository chemical environment stable. The EEG would prefer addition of clays such as commercially available bentonite to the backfill, but is willing to accept emplacement of MgO backfill for the sake of operational ease and efficiency.

As to the distinction between "engineered barriers and "engineered features", it is not based on the standard (40 CFR 191), or its criteria (40 CFR 194). The CCA (U.S. DOE, 1996c) included these "features" in the section on "engineered barriers", hence the EEG comment.

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ACRONYMS

AEC	U.S. Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
BIR	Baseline Inventory Report
CAG	Compliance Application Guidance
CAO	Carlsbad Area Office
CARD	Compliance Assessment Review Document
CCA	Compliance Certification Application
CCDF	Complimentary Cumulative Distribution Function
CH-TRU	Contact-Handled Transuranic
CRP	Cellulosics, Rubber and Plastics
DCCA	Draft Compliance Certification Application
DLR	Dewey Lake Redbeds
DOE	U. S. Department of Energy
DQC	Date Quality Characteristics
DRZ	Disturbed Rock Zone
EEG	Environmental Evaluation Group
EMP	Environmental Monitoring Plan
EOR	Enhanced Oil Recovery
EPA	U. S. Environmental Protection Agency
ERDA	Energy Research and Development Authority
HI	Human Intrusion
INEEL	Idaho National Engineering and Environmental Laboratory
IRG	International Review Group
IRT	Independent Review Teams
LANL	Los Alamos National Laboratory
LWB	Land Withdrawal Boundary

M&O	Management and Operations
MCLs	Maximum Concentration Limits
MMP	Minimum Miscibility Pressure
NAS	National Academy Science
NRC	National Research Council
NMOCD	New Mexico Oil Conservation Division
NEA/IAEA	Nuclear Energy Agency/International Atomic Energy Agency
OECD/IAEA	Organisation for Economic Cooperation and Development/International Atomic Energy Agency
OECD/NEA	Organisation for Economic Cooperation and Development/Nuclear Energy Agency
PA	Performance Assessment
PAVT	Performance Assessment Validation Test
PIC	Passive Institutional Controls
QA	Quality Assurance
QAPD	Quality Assurance Program Document
QED	Qualification of Existing Data
RTR	Real Time Radiography
RH-TRU	Remote-Handled Transuranic
SNL	Sandia National Laboratory
SWND	Southwestern Nash Draw
STP	Standard Temperature Pressure
SPM	System Prioritization Method
TRU	Transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
USDW	Underground Source of Drinking Water
U.S. NRC	United States Nuclear Regulatory Commission
VE	Visual Examination
WID	Waste Isolation Division

WIPP	Waste Isolation Pilot Plant
WQSP	Water Quality Sampling Program
WWIS	WIPP Waste Information System