EEG-68
DOE/AL/58309-68

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

March 1998

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

ACKNOWLEDGMENTS

We acknowledge the contribution made by Dr. Virginia Oversby in reviewing the actinide solubility issue, and Dr. Peter Spiegler who wrote most of the solution mining section.

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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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

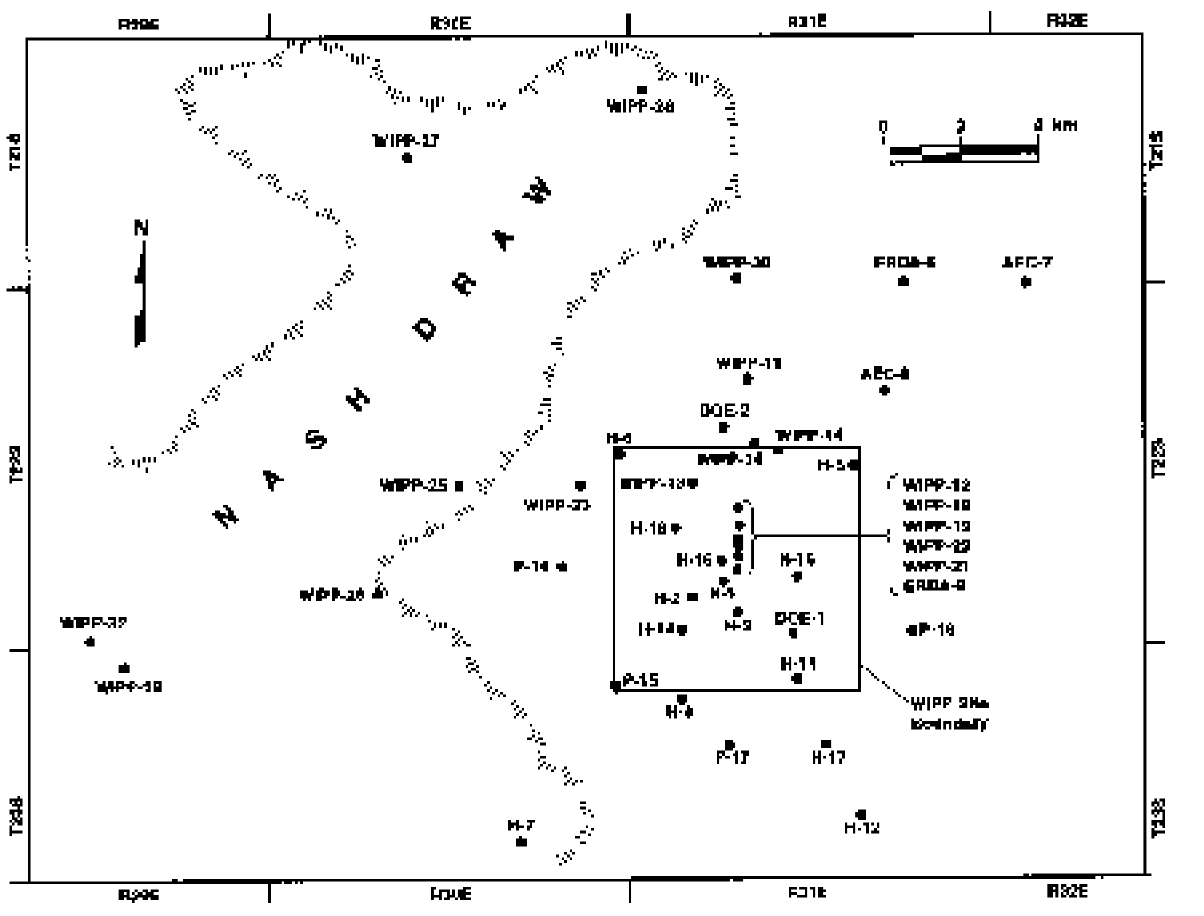


Fig. 1. Location of WIPP Boreholes

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-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 5.82×10^{-7} M, and ranged from 5.82×10^{-9} to 1.46×10^{-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 $6x10^{-9}$ M. If one assumes 100 m^3 of Pu^{239} brine, then it is expected that the release is $2.5x10^{-5}$ 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

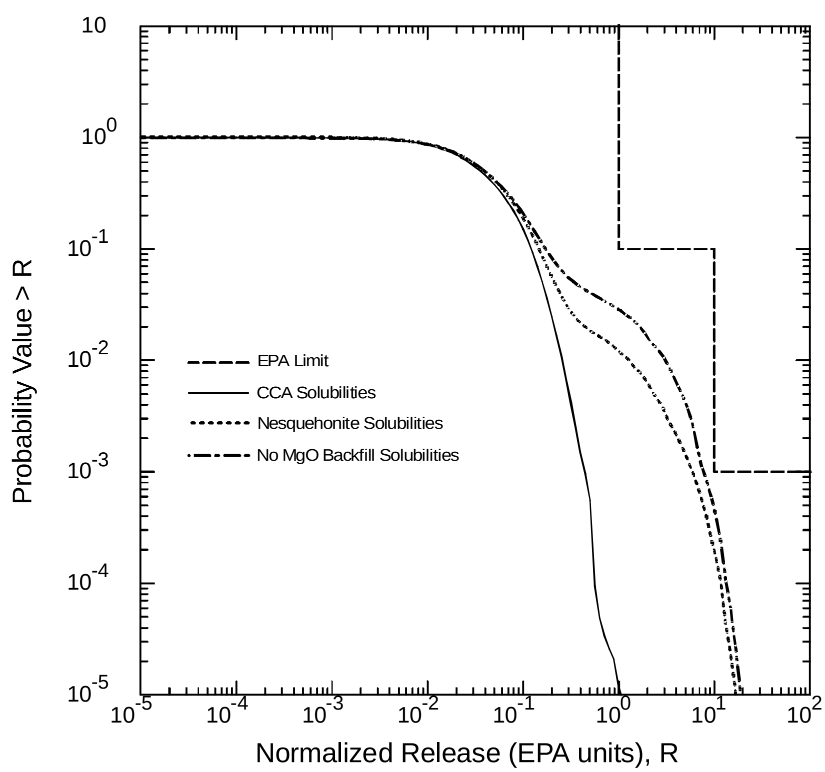


Figure 2. Overall Mean of Normalized Releases for Modeling of increased solubilities using Nesquehonite and 'No Backfill' Values compared to CCA values.

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 $1.7x10^{-14}$ m^2, $5.0x10^{-14}$ m^2, and $1.2x10^{-16}$ 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 $1.7x10^{-13}$ 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 2.4×10^{-13} m^2 be used instead of 1.7×10^{-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 1.7×10^{-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 0.8×10^{-13} to 4.4×10^{-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 0.5×10^{-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 0.5×10^{-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.

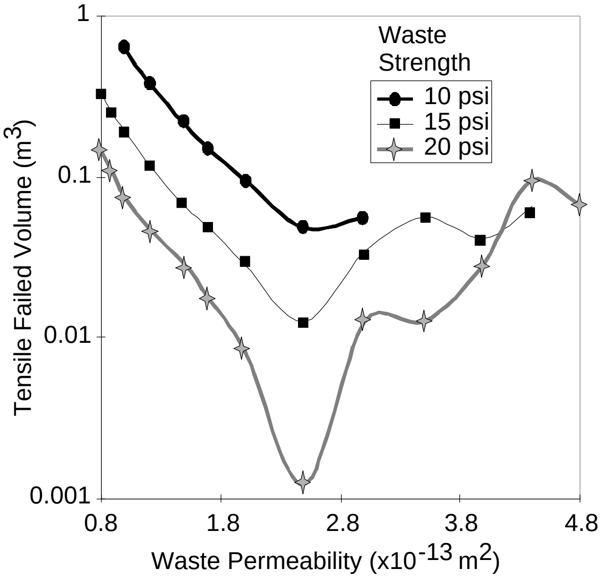


Figure 3. Contiguous Failed Volume as a Function of Increasing Waste Permeability for Different Waste Strengths With Initial Repository Pressure of 14.5 MPa.

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 $2.5x10^{-13}$ 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 $2.5x10^{-15}$ 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 $1.0x10^{-13}$ m^2 for 10 psi waste strength, and decreases to $0.8x10^{-13}$ 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 $1.7x10^{-13}$ m^2 and $2.0x10^{-13}$ 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

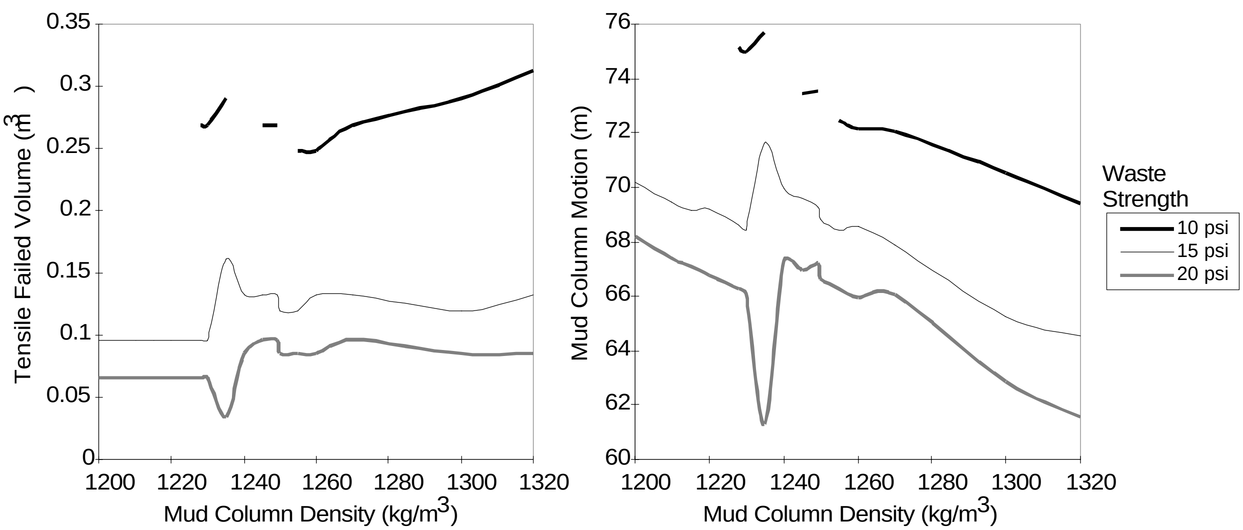


Figure 4. Left) Tensile Failed Volume as a Function of Mud Column Density for Several Waste Strengths. Right) Mud Column Motion as a Function of Mud Column Density. The Discontinuous Curve for the Low Waste Strength of 10 psi Indicates Cascading of Failed Waste at the Values Chosen for the Experiment.

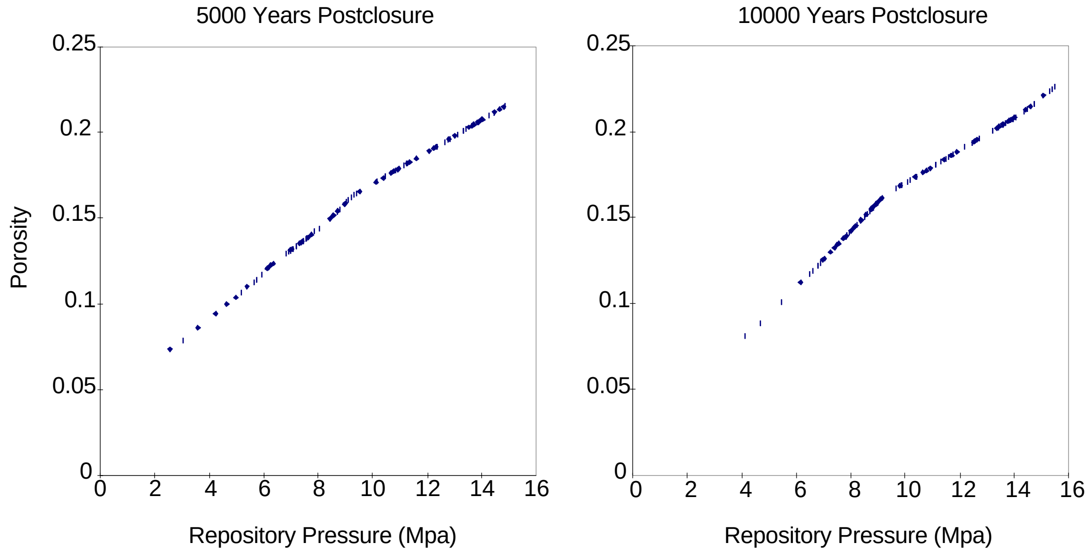


Figure 5. BRAGFLO Porosity Values Versus Pressure Profiles for Undisturbed Scenarios of the CCA.

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 $1.7x10^{-13}$ 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

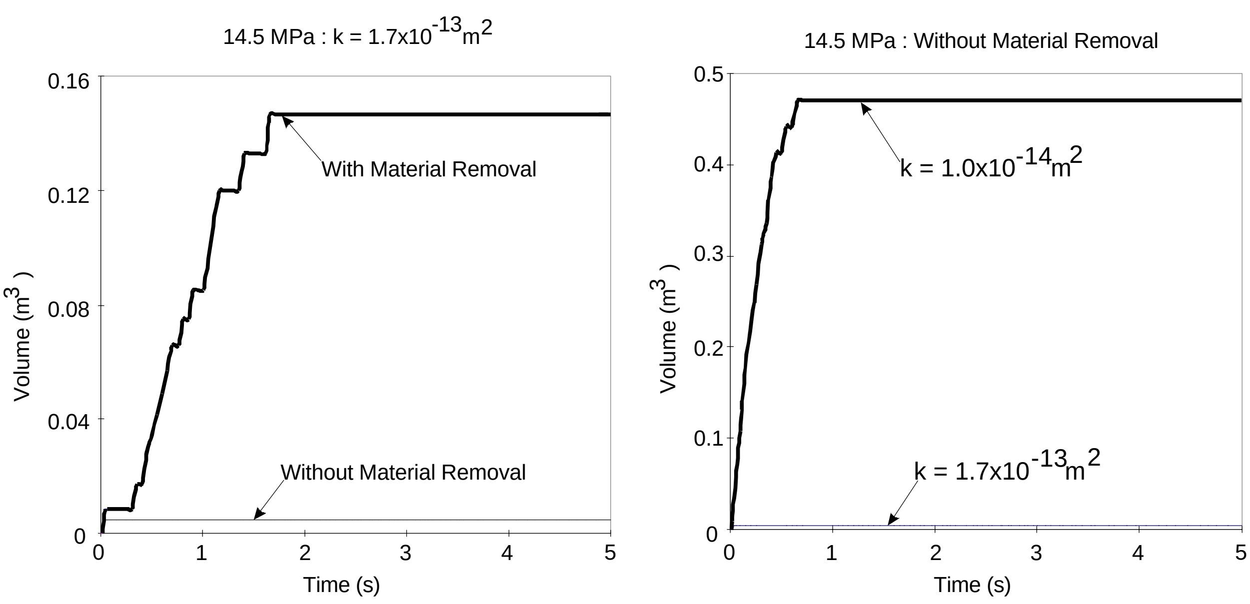


Figure 6. GASOUT Analogy Illustrating The Importance Of Considering Lower Permeabilities. Left) Constant Permeability With And Without Material Removal. Right) Without Material Removal At Two Different Permeabilities.

For an extreme example of the above analogy, Figure 7 shows radial distance of potential failure at permeabilities of $1.7x10^{-13}$ and $1x10^{-14}$ 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 $1x10^{-14}$ 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

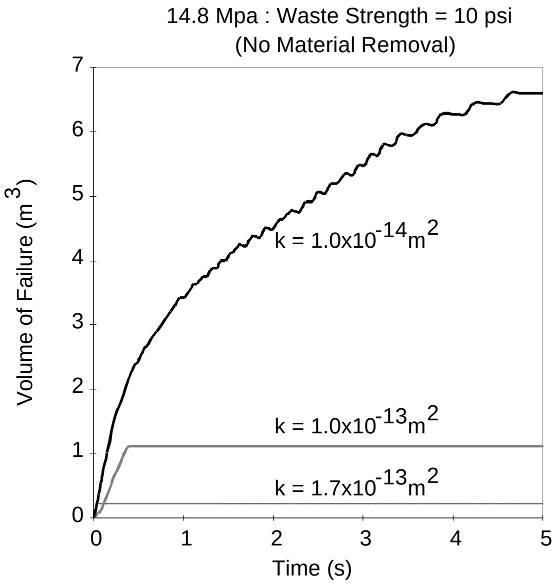


Figure 7. Failure Volume (m^3) vs Time (s) for Different Waste Permeabilities. The results are from GASOUT with the option of 'failed material removal' turned off.

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 1.7×10^{-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

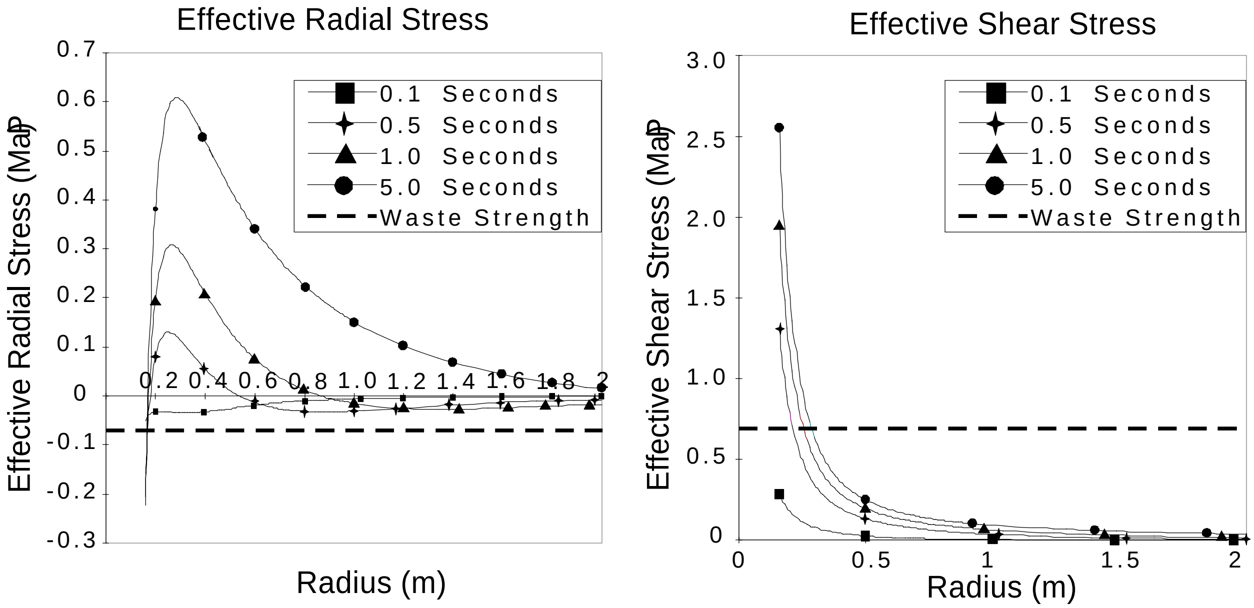


Figure 8. Computed Radial (Normal) And Shear Stresses In A Hemispherical Cavity During Spall From GASOUT, Assuming 14.5 MPa Initial Repository Pressure, 1.7×10^{-13} m^2 Waste Permeability, And No Material Removal From Failure.

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.

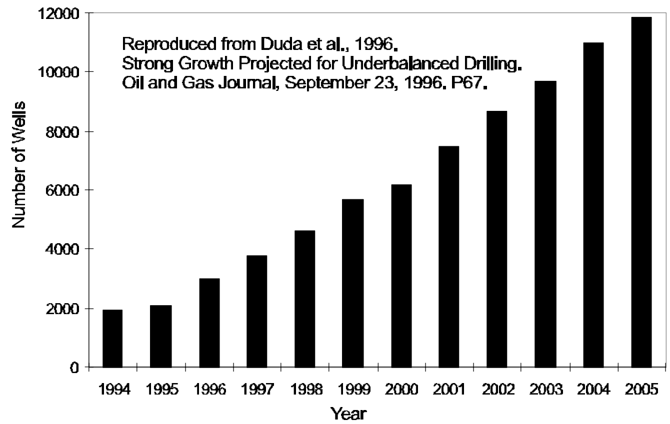


Fig. 9. DOE's projected use of underbalanced drilling in the United States.

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.

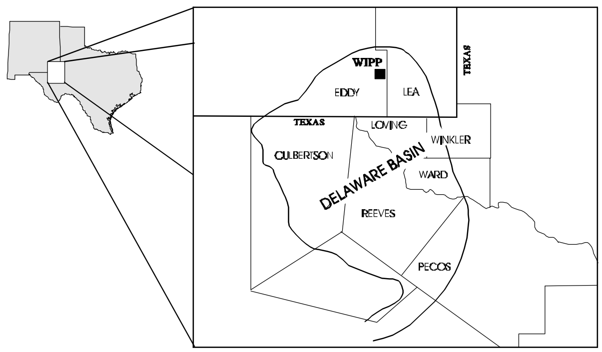


Fig 10. New Mexico and Texas Counties in the Delaware Basin

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 σ' 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

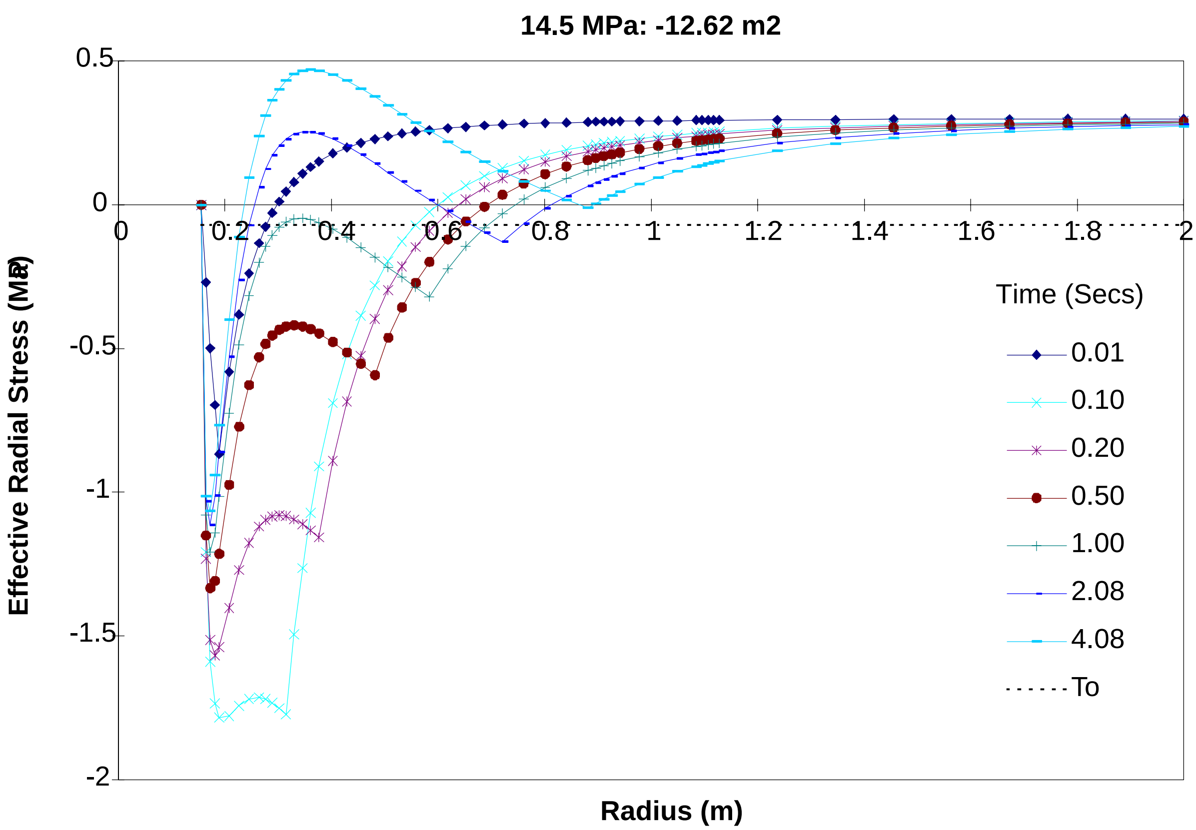


Figure 11. Effective Radial Stress As A Function Of Radial Distance For The EPA's Air Drilling Analysis.

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

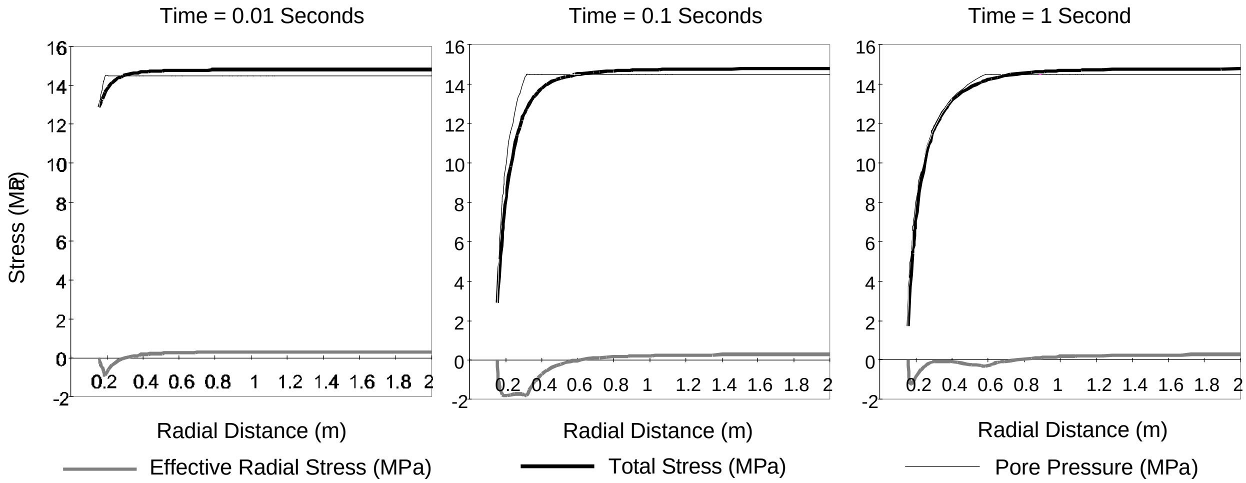


Figure 12. Effective Stress, Total Stress, and Pore Pressure Profiles in the waste at three independent times from the EPA's Analysis of Air Drilling.

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.

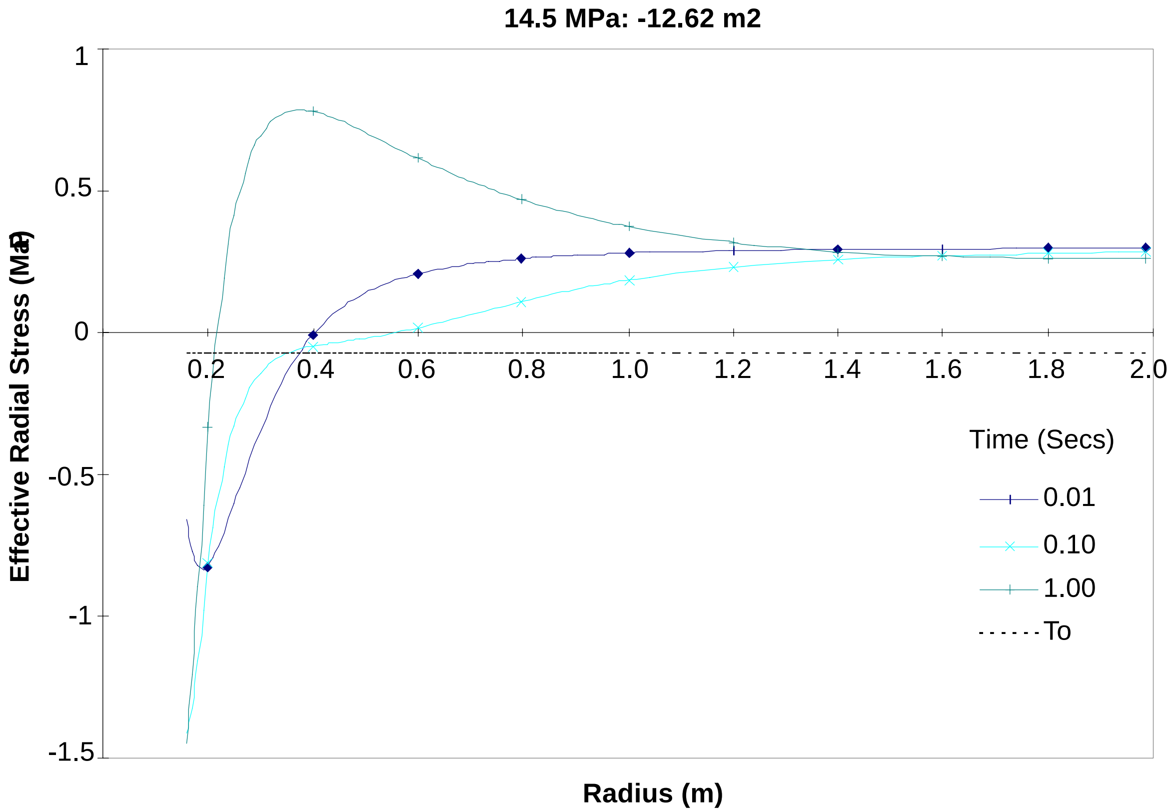


Figure 13. Effective Radial Stress As A Function Of Radial Distance Using GasOut For The Air Drilling Analysis.

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.

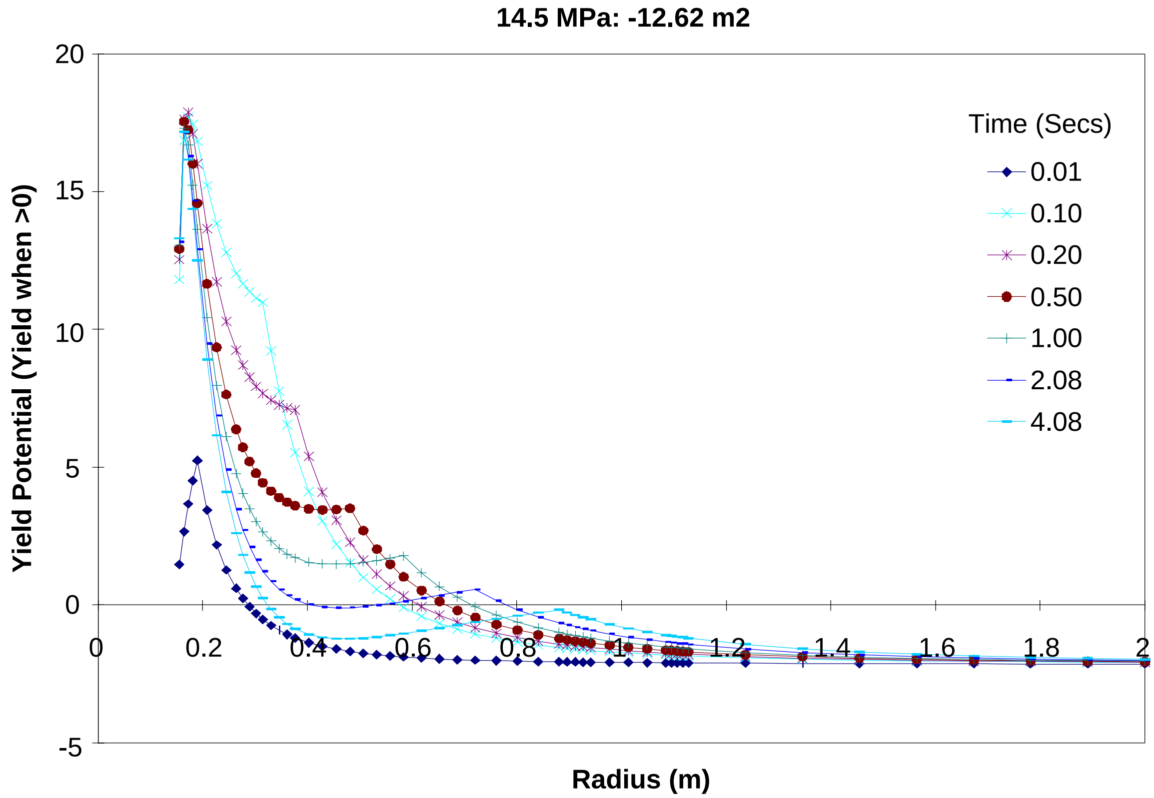


Figure 14. Yield Potential for EPA Air Drilling Analysis. The Figure Represents Equation 2 (above) vs. Radial Distance. Yield Will Occur When the Potential is Greater than Zero.

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

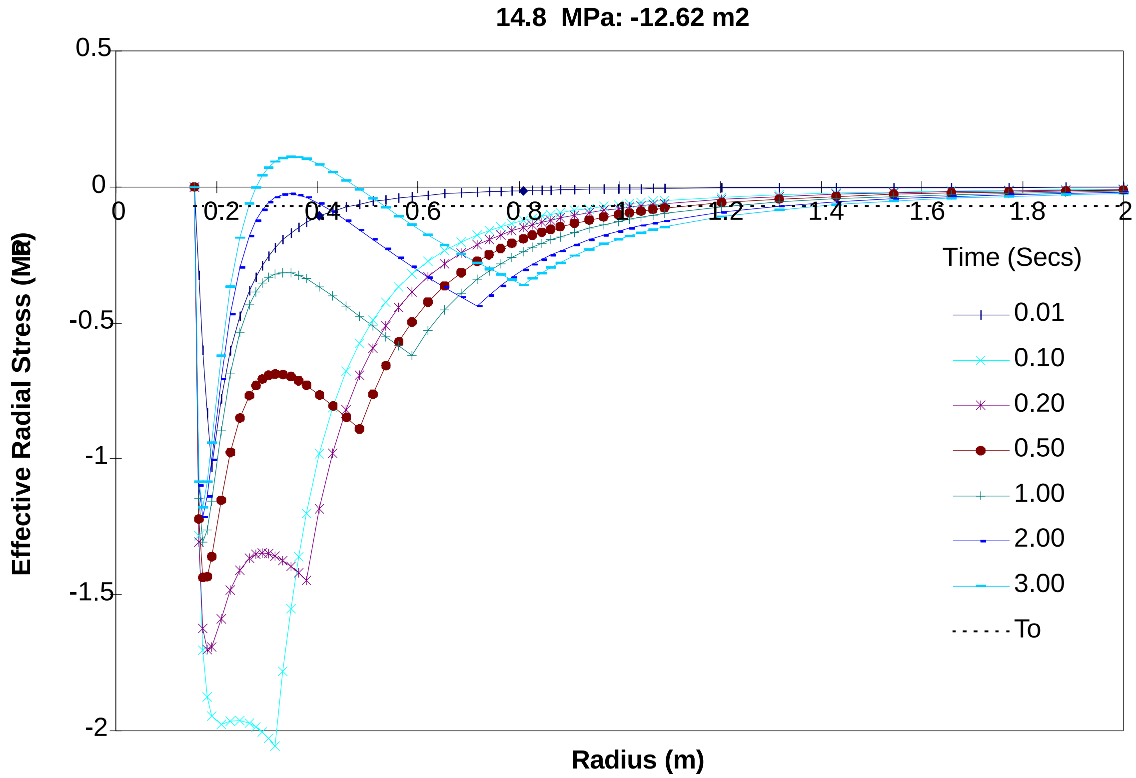


Figure 15. Effective Radial Stress As A Function Of Radial Distance For An Increased Pressure For The Air Drilling Scenario.

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 10×10^{-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
$2.4 \times 10^{-13} m^2$	1.38 m^3		
1.7×10^{-13} m^2	1.26 m^3	1.43 m^3	
1.0×10^{-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).

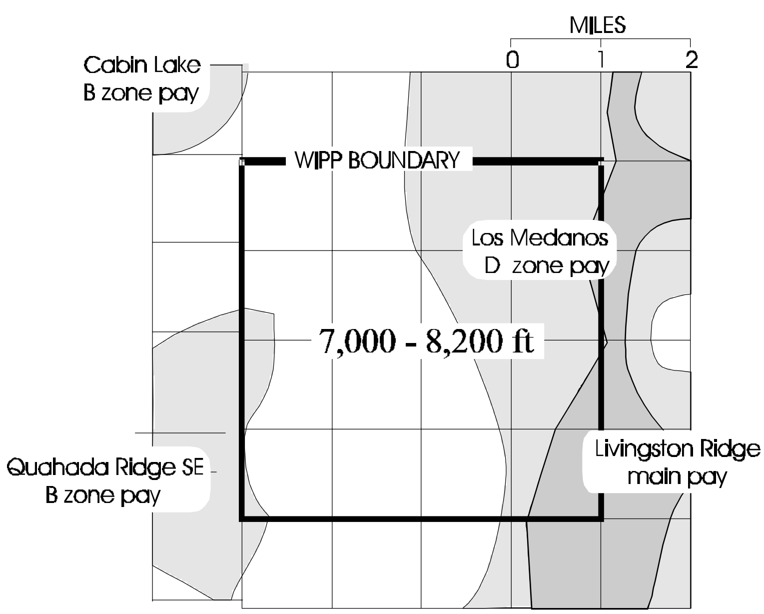


Fig. 16. Areas of Known and Probable Oil And Gas Resources for Delaware Pools. Broadhead et al., 1996.

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.

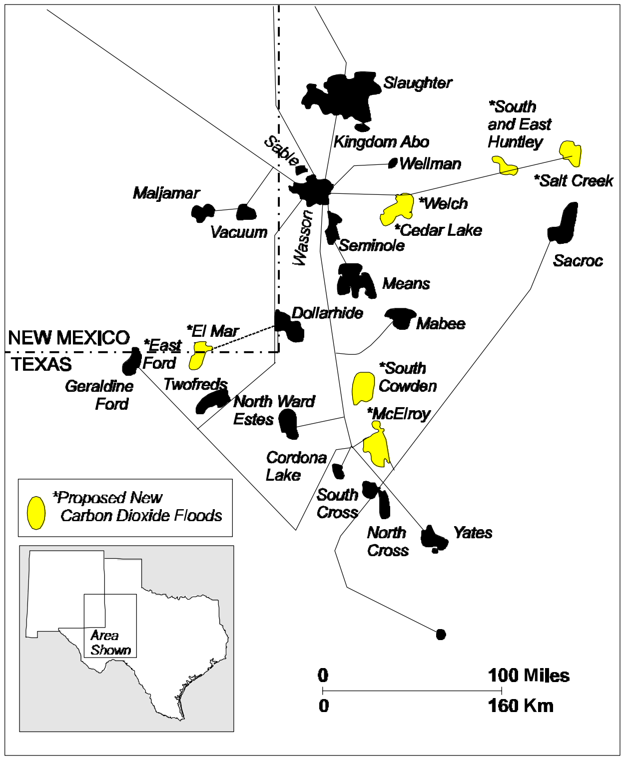


Fig. 17. Permian Basin CO_2 Pipelines and CO_2 Floods (Moritis 1993; Silva 1996)

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.

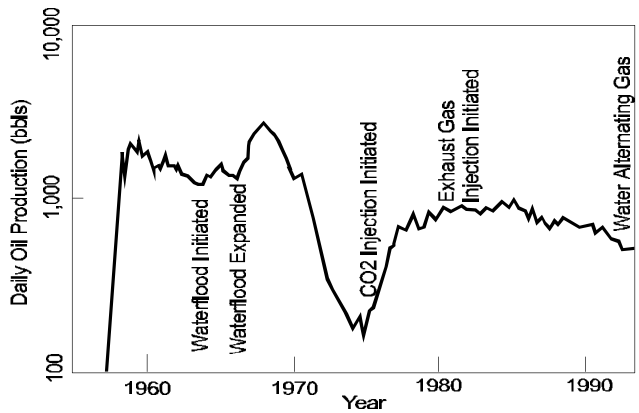


Fig. 18. Production History of Twofreds (After Flanders and DePauw 1993).

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

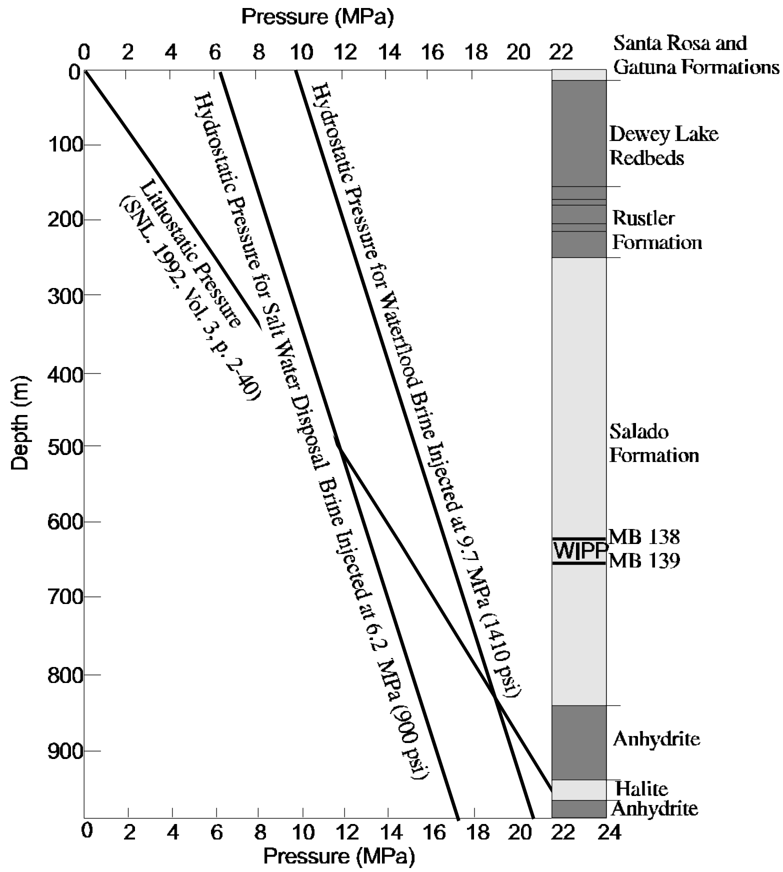


Fig. 19. Comparison of Approved Injection Pressures For Salt Water Disposal Well Versus Oil Field Water Flood Wells Near WIPP.

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

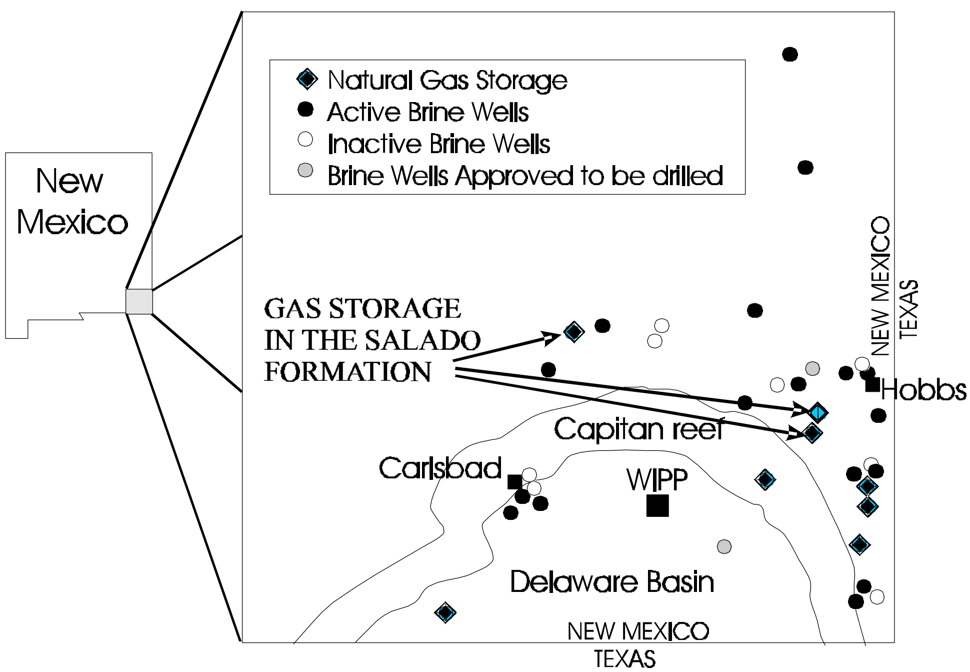


Fig. 20. Solution Mining of Brine and Natural Gas Storage Wells.

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 $5x10^{-3}$ 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.

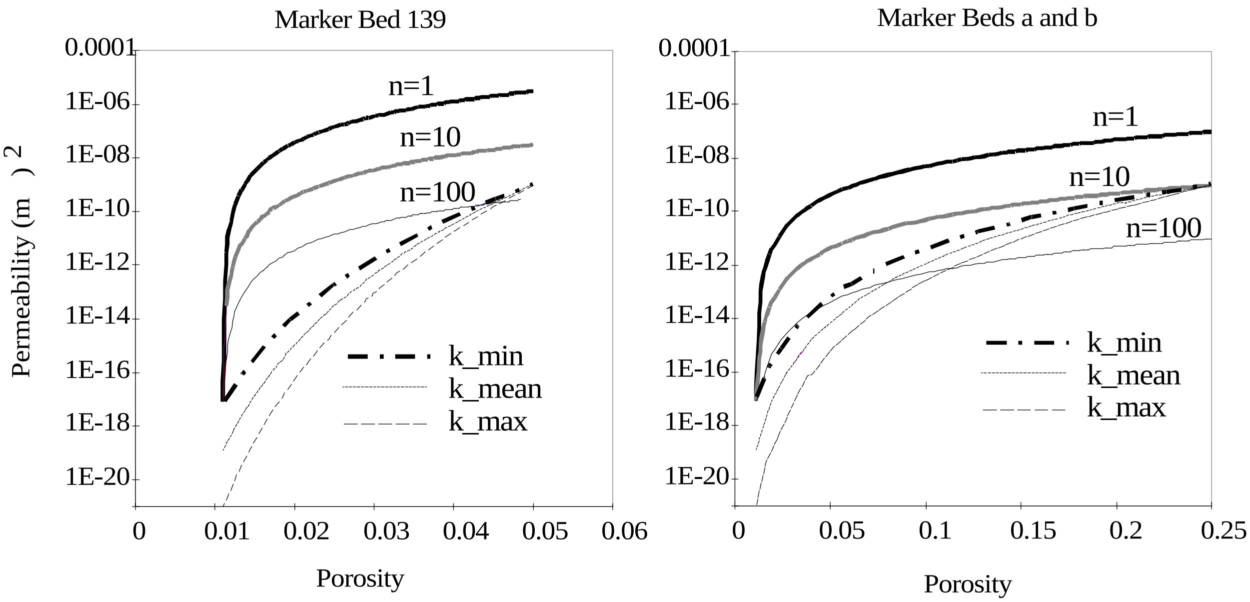


Fig. 21. Permeability vs. Porosity Model With BRAGFLO for Left) Marker Bed 139 and Right) Marker Beds a and b.

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

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

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

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

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

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

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

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

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

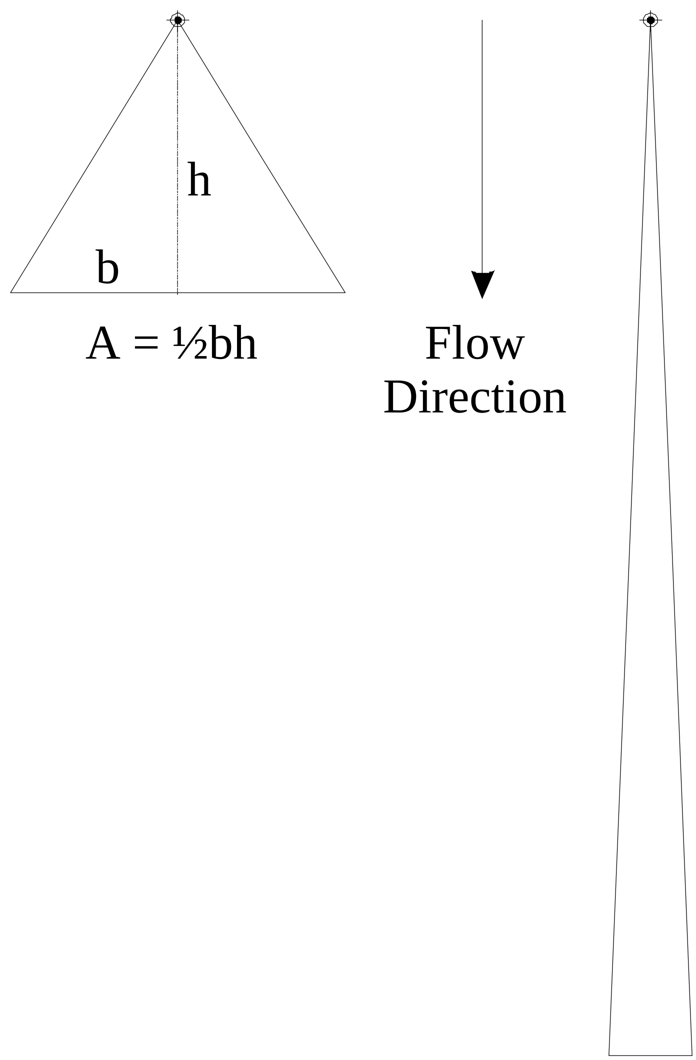


Fig. 22. Conceptual Diagram Of Contaminant Plumes Represented As Simple Triangles, Showing Different Travel Distances For A Relatively Wide Plume Compared To That Of A Relatively Narrow Plume, Where Both Plumes Encompass Equal Volumes Of Fluid And Equal Masses Of Solute.

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

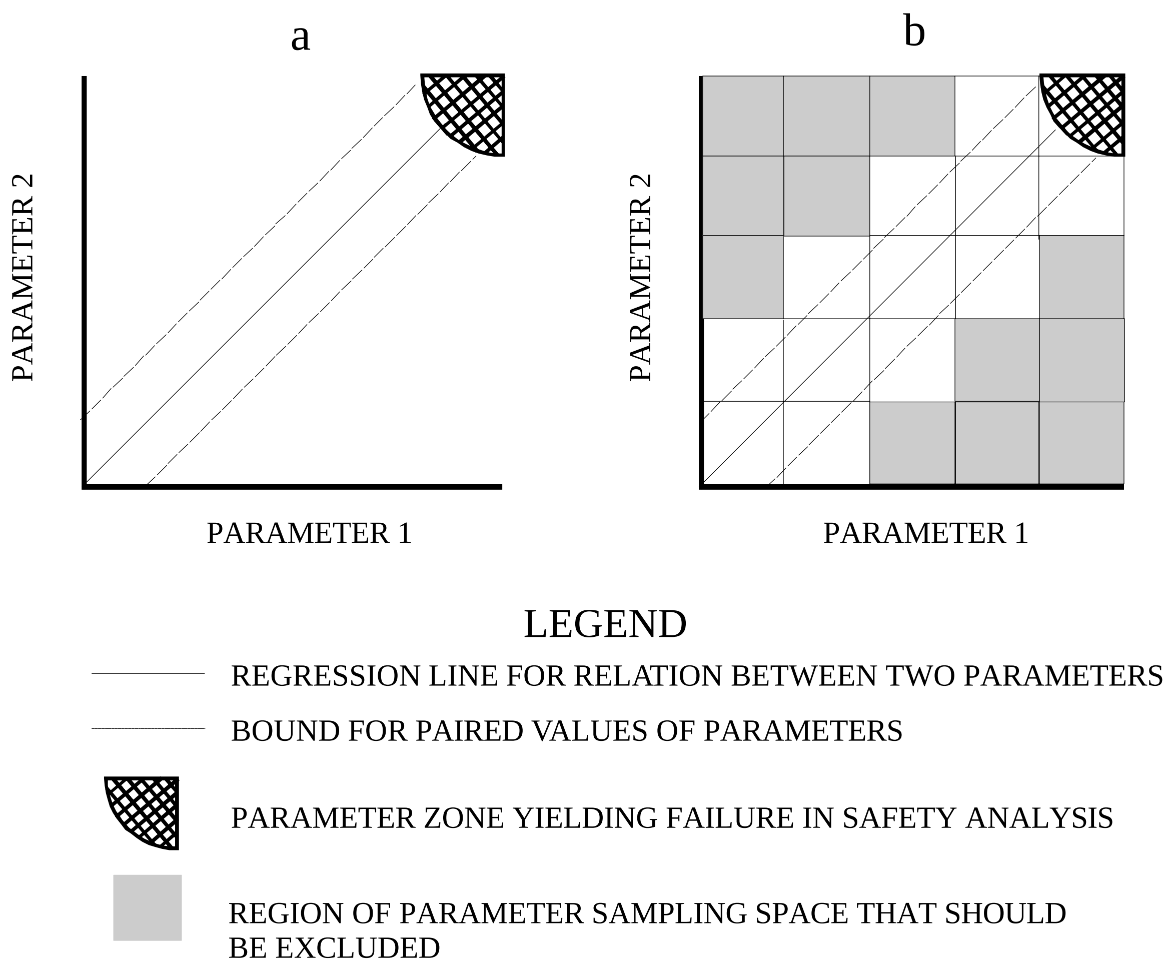


Fig. 23. Example to illustrate effect on calculated risk of independent sampling values of two parameters that are strongly correlated. (a) All data points fall within indicated bounds. (b) Independent sampling can yield paired values that are “out of bounds” and should be excluded from the PA.

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.

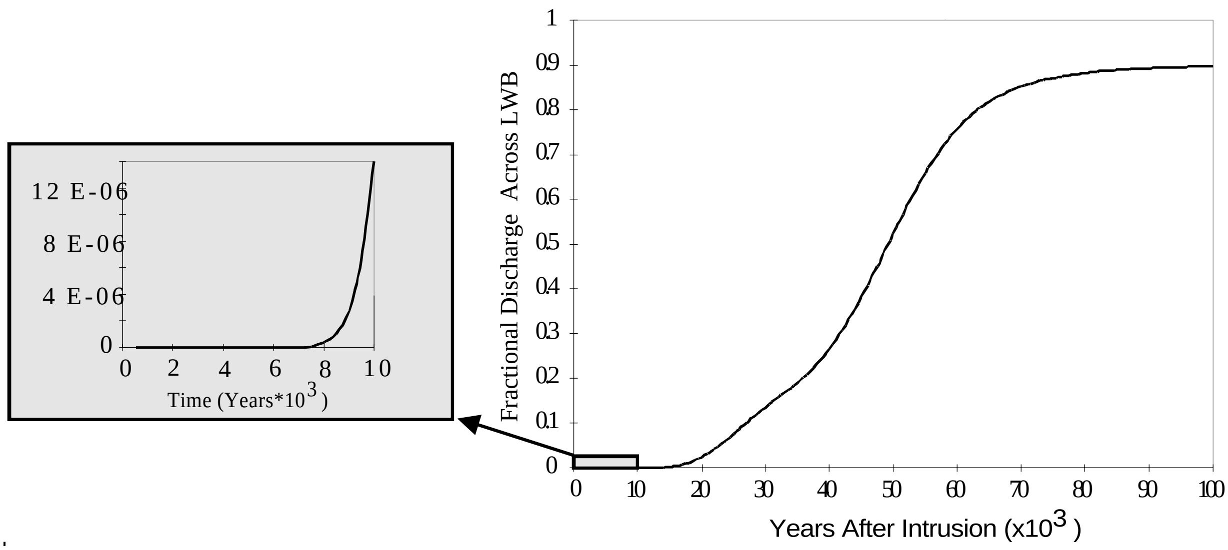


Fig. 24. Fractional Discharge Of Uranium Across The LWB Within 100,000 Years, With Blowout Section Of 10,000 Years. Reproduced from Rucker (1998).

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.

<u>Effect on Cuttings Releases</u>. 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.

<u>Effect on Spallings Releases</u>. 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 2.1×10^7 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 2×10^7 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.

---

[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.

<u>Topographical Characteristics</u>. §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.

[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.

.

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 $2.4x10^{-13}$ m^2 and not $1.7x10^{-13}$ 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.

7.0 REFERENCES

American Society of Mechanical Engineers. 1977. Quality Assurance Program Requirements for Nuclear Facilities. New York, NY: American National Standards Institute, ANSI/ASME NQA-45.2-1977.

American Society of Mechanical Engineers. 1989. Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories. New York, NY: American National Standards Institute, ANSI/ASME NQA-3-1989.

American Society of Mechanical Engineers, 1990. Quality Assurance Requirements for Nuclear Facility Applications, 1990 Addenda, Part 2.7 to ASME NQA-2-1989 ed. New York, NY: American National Standards Institute, ANSI/ASME NQA-2a-1990.

American Society of Mechanical Engineers. 1994. Quality Assurance Program Requirements for Nuclear Facilities. New York, NY: American National Standards Institute, ANSI/ASME NQA-1-1994.

Bailey, J. 1990. August 13 memorandum on water level rises in the Culebra Dolomite monitor wells from J. Bailey, petroleum engineer at the New Mexico State Land Office to Marsh LaVenue, Interra Consulting Company and contractor to Sandia National Laboratories.

Beauheim, R.L. 1987. Interpretation of the WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) site. Sandia National Laboratories, SAND87-2456.

Beauheim, R. L. 1989. Interpretation of H-11B4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND89-0536.

Beauheim, R. L. 1990. January 12 report from R. L. Beauheim on recent rise in the Culebra water levels around the WIPP site to the Sandia National Laboratories Fluid Flow and Transport Division 6344.

Beauheim, R.L. 1996. "Observations of water level rises in the Culebra Aquifer," in Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis, by Matthew K. Silva. Albuquerque, NM: Environmental Evaluation Group, EEG-62, 39-62.

Beauheim, R.L. 1997. January 16 memorandum from R. L. Beauheim to Palmer Vaughn on "Revisions to Castile Brine Reservoir Parameter Packages," Sandia National Laboratories, WPO#9882.

Beauheim, R.L. and R.M. Holt. 1990. "Hydrogeology of the WIPP site," in Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Field Trip #14 Guidebook. Geological Society of America 1990 Annual Meeting. Dallas, TX: Dallas Geological Society.

Berglund, J.W. 1994. Memorandum of record. "The Direct Removal of Waste Caused by a Drilling Intrusion into a WIPP Panel - a Position Paper." Sandia National Laboratories, WPO#9882.

Blaine, R.L. 1997. Evaluation of Minimum K_d Parameter Values for Culebra Transport. Sandia National Laboratories, WPO#43944.

Boneau, D. 1992. March 17 affidavit in support of the application of Yates Petroleum Corporation for administrative review by the Bureau of Land Management State Director of Decisions of the BLM Carlsbad Area Manager denying four applications for permit to drill wells in Sections 11 and 14, T22S, R31E.

Bredehoeft, J.D. 1997a. Air Drilling into WIPP. La Honda, CA: Hydrodynamics Group.

Bredehoeft, J.D. 1997b. Hartman Scenario Implications for WIPP. La Honda, CA: Hydrodynamics Group.

Bredehoeft, J.D. 1997c. July 28 memorandum, Rebuttal: Technical Review of The Hartman Scenario Implications for WIPP (Bredehoeft, 1997) by Swift, Stoelzel, Beauhiem, and Vaughn - June 13, 1997, Hydrodynamics Group, La Honda, CA.

Bredehoeft, J.D. and W. Gerstle. 1997. The Hartman Scenario Revisited Implications for WIPP. La Honda, CA: The Hydrodynamics Group.

Broadhead, R.F., F. Luo and S.W. Speer. 1996. "Evaluation of oil and gas resources at the WIPP site. Synopsis and presentation," in Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis, by Matthew K. Silva. Albuquerque, NM: Environmental Evaluation Group, EEG-62, 21-37.

Broadhead, R.F., F. Luo and S.W. Speer. 1995. Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Carlsbad, NM: Westinghouse Electric Corporation, Waste Isolation Division, vol. 3, chap. XI.

Brown, J. 1995. "Cabin Lake, field summary," in Symposium of the Oil and Gas Fields of Southeastern New Mexico. Roswell, NM: Roswell Geological Society, 191-193.

Brush, L.H. 1990. June 22 memorandum from L. H. Brush, Sandia National Laboratories to V. Daub, DOE WIPP Project Office.

Brush, L.H. and D.R. Anderson. 1989. February 14 internal Sandia National Laboratories memorandum to B. Butcher on estimates of gas production rates, potentials, and periods, and dissolved radionuclide concentrations for the WIPP Supplemental Environmental Impact Statement.

Brush, L.H. and A.R. Lappin. 1990. August 1 internal Sandia National Laboratories memorandum to D.R. Anderson on additional estimates of gas production rates and radionuclide solubilities for use in models of WIPP disposal rooms. memo 4 in SAND89-2408.

Bureau Of Land Management Roswell District. 1993. Preliminary Map Showing Distribution Of Potash Resources, Carlsbad Mining District, Eddy And Lea Counties, New Mexico.

Butcher, B.M. 1989. Waste Isolation Pilot Plant Simulated Waste Compositions and Mechanical Properties. Sandia National Laboratories, SAND89-0372.

Butcher, B.M. 1990. July 24 memorandum from B. M. Butcher to M. G. Marietta, on disposal room porosity and permeability values for disposal room performance assessment, Sandia National Laboratories.

Butcher, B.M., T.W. Thompson, R.G. VanBuskirk and N.C. Patti. 1991. Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste. Sandia National Laboratories, SAND90-1206.

Campbell, J.M., E.S. Walker and A.L. Porter. 1964. New Mexico Oil Conservation Commission Order Approving Application of Texaco Inc. for a Waterflood Project, Lea County, New Mexico. Case No. 3086. Order No. R-2748 July 29.

Cargo, D.F., A.J. Armijo and A.L. Porter. 1969. New Mexico Oil Conservation Commission Order Approving Application of Texaco Inc. for a Waterflood Expansion and Amendment of Order No. R-2748, Lea County, New Mexico. Case No. 4271. Order No. R-2748-A, December 3.

Chan, D.Y., B.D. Hughes and L. Paterson. 1993. "Transient gas flow around boreholes." Transport in Porous Media 10: 137-152.

Chapman, J.B. 1986. Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area. Santa Fe, NM: Environmental Evaluation Group, EEG-35.

Chapman, J.B. 1988. Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico. Santa Fe, NM: Environmental Evaluation Group, EEG-39

Chaturvedi, L. 1980. WIPP Site and Vicinity Geological Field Trip. A Report of a Meeting Held on January 17-18, 1980. Santa Fe, NM: Environmental Evaluation Group, EEG-7.

Chaturvedi, L. 1984. Occurrence of Gases in the Salado Formation. Santa Fe, NM: Environmental Evaluation Group, EEG-25.

Chaturvedi, L. 1993. "WIPP-related geological issues," in Carlsbad Region, New Mexico and West Texas New Mexico Geological Society Guidebook, 44th Field Conference, October 6-9, 1993. Socorro, NM: New Mexico Geological Society, 331-338.

Chaturvedi, L. and J.K. Channell. 1985. The Rustler Formation as a Transport Medium for Contaminated Groundwater. Santa Fe, NM: Environmental Evaluation Group, EEG-32.

Chaturvedi, L., W. W.-L. Lee, M.K. Silva, T.M. Clemo and R.H. Neill. 1997. "Evaluation of the long-term integrity of WIPP," in the WM '97 Proceedings: HLW, LLW, Mixed Wastes and Environmental Restoration - Working Towards a Cleaner Environment, March 2-6, 1997. Tucson, AZ: WM Symposia, Inc., 10-04.

Colome, J. and D. Ruse. 1994. Operation of a Potassium Ore Pilot Cavern. Meeting paper, presented at the SMRI-Fall meeting in 1994 Hannover, Germany. Woodstock, IL: Solution Mining Research Institute.

Cone, L.M. 1996. May 28 letter from L.M. Cone, U.S. BLM Roswell District Manager to William J. LeMay, Director of the New Mexico Oil Conservation Division.

Cook, A.M., L.R. Myer, N.G.W. Cook and F.M. Doyle. 1990. "The effects of tortuosity on flow through natural fractures," in Rock Mechanics Contributions and Challenges, by Hustrulid and Johnson. Rotterdam, Netherlands: A. A. Balkema.

Cross, J.E., F.T. Ewart and B.F. Greenfield. 1989. "Modeling the behavior of organic degradation products," in Scientific Basis for Nuclear Waste Management XII: Symposium held October 10-13, 1988, ed. W. Lutze and R. C. Ewing. Pittsburgh, PA: Materials Research Society, 715-722.

D'Appolonia Consulting Engineers, Inc. 1982. Data File Report: ERDA-6 and WIPP-12 Testing. Albuquerque, NM: Westinghouse Electric Corporation.

D'Appolonia Consulting Engineers, Inc. 1983. Geotechnical Field Data Report No. 4: Geological Mapping and Water Inflow Testing in the SPDV Ventilation Shaft. Albuquerque, NM: Westinghouse Electric Corporation.

Davis, J.G. and D.A. Shock. 1970. "Solution mining of thin bedded potash." Mining Engineering, (July): 106-109.

Davis, S. 1997. Eddy Potash to Close. Current Argus, Newspaper Serving Eddy County, New Mexico, September 26.

Davis, S.N. and E. Murphy. 1987. Dating Ground Water and the Evaluation of Repositories for Radioactive Wastes. U.S. Nuclear Regulatory Commission, NUREG/CR-4912.

DePablo, J., J. Gimenez, M.E. Torrero and I. Casa. 1995. "Mechanism of unirradiated UO_2 (s) dissolution in NaCl and $MgCl_2$ brines at 25° C," in Scientific Basis for Nuclear Waste Management XVIII; Symposium held October 23-27, 1994, Kyoto, Japan, ed. T. Murakami and R. C. Ewing. Pittsburgh, PA: Materials Research Society, 609-615.

Dials, G. 1997a. January 24 letter from G. Dials, U.S. Department of Energy, to R. Trovato, U.S. Environmental Protection Agency, second response package to EPA's letter of December 19, 1996.

Dials, G. 1997b. September 16 letter with attachment from G. Dials, DOE to W. Gerstle, response to a December 3, 1996, letter on gas-driven cracking in WIPP rock salt.

Dials, G. 1997c. June 13 letter from G. Dials, Manager, DOE/CAO to R. Neill, Director, EEG.

Dials, G. 1997d. March 12 letter from G. Dials, DOE to R. Trovato, EPA, EPA Docket A-93-02, II-H-24.

Diamon, H.W. Jr. 1985. "The Solution Mining Research Institute - an update", in Sixth International Symposium on Salt, Toronto, Ontario, Canada, May 24-28, 1983, ed. B. C. Schreiber and H. L. Harner. Alexandria, VA: Salt Institute, 2: 5-10.

Duchrow, G., J. Fitz and N. Gruschow. 1990. "Possibilities for profitable carnallitite extraction in East Germany." Phosphorus & Potassium, no. 168 (May-June): 26-32.

Duda, J.R., G.H. Medley, Jr. and W.G. Deskins. 1996. "Strong growth projected for underbalanced drilling." Oil and Gas Journal Special, (September 23): 67-77.

Duke Engineering & Services. 1997. Exhaust Shaft: Phase 2 Hydraulic Assessment Data Report Involving Drilling, Installation, Water-Quality Sampling, and Testing of Piezometers 1-12. Westinghouse Waste Isolation Division, DOE/WIPP97-2278.

Dutton, S.P., S.D. Hovorka and A.G. Cole. 1996. Application of Advanced Reservoir Characterization, Simulation and Production Optimization Strategies to Maximize Recoveries in Slope and Basin Clastic Reservoirs, West Texas (Delaware Basin) Annual Report, March 31, 1995 to March 30, 1996. U.S. Department of Energy, DOE/BC/14936-5.

Dutton, S.P., G.B. Asquith, M.D. Barton, A.G. Cole, J. Gogas, M.A. Malik, S.J. Clift and J.I. Guzman. 1997. Application of Advanced Reservoir Characterization, Simulation and Production Optimization Strategies to Maximize Recoveries in Slope and Basin Clastic Reservoirs, West Texas (Delaware Basin) Annual Report, March 31, 1996 to March 30, 1997. U.S. Department of Energy, DOE/BC/14936-9.

Environmental Evaluation Group. 1983. EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983. Santa Fe, NM: Environmental Evaluation Group, EEG-22.

Felmy, A.R., D. Rai, J.A. Schramke and J.L. Ryan. 1989. "The solubility of plutonium hydroxide in dilute solution and in high-ionic-strength brines." Radiochimica Acta 48: 29-35.

Flanders, W.A. and R.M. DePauw. 1993. "Update case history: performance of the Twofreds tertiary CO_2 project," in Proceedings of the SPE Annual Technical Conference/Reservoir Engineering, Houston, Texas, October 3-6. Richardson, TX: Society of Petroleum Engineers, SPE 26614.

Francis, A.J., J.B. Gillow and M.R. Giles. 1997. Microbial Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions. Sandia National Laboratories, SAND96-2582.

Freeze, G.A., K.W. Larson and P.B. Davies. 1995. Coupled Multiphase Flow and Closure Analysis of Repository Response to Waste Generated Gas at the Waste Isolation Pilot Plant (WIPP). Sandia National Laboratories, SAND93-1986.

Gaisbauer, E. 1997. "850 years solution mining in Altaussee, Austria," meeting paper, presented at the Salinen Austria GmbH in Cracow, Poland, May 11-14, 1997. Deerfield, IL: Solution Mining Research Institute.

Gallegos, J.E. and M.J. Condon. 1994. Plaintiffs' Motion in Limine Prohibiting Texaco from Offering Opinions of John F. Pickens Based on Waterflows in the WIPP Area. Hartman vs. Texaco. November 22, 1994. Hartman vs. Texaco. No. SF 93-2387(C), First Judicial District, County of Santa Fe, State of New Mexico.

Gerstle, W. 1996. December 3 letter from W. Gerstle to H. O'Leary in EPA Docket A-93-02, II-H-01.

Gerstle, W. 1998. Private communication.

Gerstle W. and J. Bredehoeft. 1997. Linear Elastic Model for Hydrofracture at WIPP and Comparison with BRAGFLO. La Honda, CA: Hydrodynamics Group.

Gerstle, W., F. Mendenhall and W. Wawersik. 1996. Prediction of Gas-Driven Hydrofractures at WIPP. Albuquerque, NM: University of New Mexico, Department of Civil Engineering.

Greenfield, B.F., A.D. Moreton, M.W. Spindler, S.J. Williams and D.R. Woodwark. 1992. "The effects of the degradation of organic materials in the near field of a radioactive waste repository." Scientific Basis for Nuclear Waste Management XV: a Symposium held November 4-7, 1991, Strasbourg, France, ed. C. G. Sombret. Pittsburgh, PA: Materials Research Society, 299-306.

Griswold, G.B. 1977. Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM. Albuquerque, NM: Sandia National Laboratories, SAND77-0946.

Gross, M.B. and T.W. Thompson. 1997. Analysis Package for the Semi-Analytical Calculations Conducted in Support of an Alternative Spallings Model: Method II - the Quasi-Static Model. Albuquerque, NM: Sandia National Laboratories, WPO#47388.

Gruschow, N. 1992. "Solution mining of potash ore," meeting paper, presented at the SMRI Meeting in Houston, Texas, Oct 18-23, 1992. Woodstock, IL: Solution Mining Research Institute.

Hansen, F.D., M.K. Knowles, T.W. Thompson, M. Gross, J.D. McLennan and J.F. Schatz. 1997. Description and Evaluation of a Mechanistically Based Conceptual Model for Spall. Sandia National Laboratories, SAND97-1369.

Harms, J.C. and C.R. Williamson. 1988. "Deep-water density current deposits of Delaware mountain group (Permian), Delaware Basin, Texas and New Mexico." American Association of Petroleum Geologists Bulletin 72 (3). 299-317.

Hartman, D. 1993. November 22 letter to Sandia National Laboratories transmitting a copy of a Complaint of Trespass, Nuisance, and Waste filed in the Federal Court for the District of New Mexico, CIV93 1349M.

Helton, J. 1996. Memo: Preliminary summary of uncertainty and sensitivity analysis results obtained in support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Sandia National Laboratories.

Helton, J.C., J.W. Garner, R.P. Rechard, D.K. Rudeen and P.N. Swift. 1992. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND91-0893/1.

Herrera, S. 1995. January 20 First Judicial District, County of Santa Fe, State of New Mexico, Case No. SP 93-2387 (C), judgment in Hartman vs. Texaco.

Heyn, D.W. 1997a. February 24 letter from D. W. Heyn, IMC Kalium to R. F. Weiner, Sandia National Laboratories on potash solution mining at WIPP site.

Heyn, D.W. 1997b. February 26 letter from D. W. Heyn, IMC Kalium to Environmental Protection Agency, Docket A-93-02, potash solution mining on WIPP reservation

Hicks, T.W. 1997. March 7 memorandum from T. W. Hicks, Galson Sciences Ltd. To P. N. Swift, Sandia National Laboratories on solution mining for potash.

Holt, R.M. and D.W. Powers. 1988. Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. Westinghouse Electric Corporation, DOE/WIPP-88-004.

Howard, B.A. 1996. April 3 memo from B.A. Howard, Westinghouse Electric Corporation to Mel Marietta, Sandia National Laboratory, future mining event in the performance.

Hummel, W. 1993. Organic Complexation of Radionuclides in Cement Pore Water: A Case Study. Paul Scherrer Institut Report TM-41-93-03, PES-93-617. Sandia National Laboratories, WPO#47516.

Hussain, N. and S. Krishnaswami. 1980. "U-238 series radioactive disequilibrium in groundwaters: implication to the origin of excess U-234 and fate of reactive pollutants." Geochimica et Cosmochimica Acta 44: 1287-1291.

IMC Global, Inc. 1996. Annual Report 1996, Serving the Next Agricultural Revolution. Northbrook, IL: IMC Global, 26, 27.

Jackson, D. 1973. "Solution mining pumps new life into Cane Creek potash mine." Engineering and Mining Journal, (July) : 59-69.

Jacobs, L. 1998. "Texaco wins tax break," Hobbs News Sun, 19 February, pp. 1, 5.

Jaeger, J.C. and N.G.W. Cook. 1976. Fundamentals of Rock Mechanics, 2nd edition. London: Chapman and Hall.

Jeremic, M.L. 1994. Rock Mechanics in Salt Mining. Rotterdam, Netherlands: A.A. Balkema. chap. 13.

Jones, R.W. 1968. "Hard-to-flood sand gives up secondary oil in West Texas." World Oil, (September) : 72-76.

Kehoe, L. 1996. April 29 letter from L. Kehoe, Assistant Commissioner of New Mexico Public Lands to William J. LeMay, Director of the New Mexico Oil Conservation Division.

Kenney, J.W. and S.C. Ballard. 1990. Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989. Albuquerque, NM: Environmental Evaluation Group, EEG-47.

Kirkes, G.R. and R.D. Evans. 1997. Injection Methods: Current Practices and Failure Rates in the Delaware Basin. U.S. Department of Energy, DOE/WIPP-97-2240.

Kirkpatrick, R.K., W.A. Flanders and R.M. DePauw. 1985. "Performance of the Twofreds CO_2 injection project," in Proceedings of the 60th Society of Petroleum Engineers Annual Technical Conference, Las Vegas, Nevada September 22, 1985. Richardson, TX: Society of Petroleum Engineers, 89-101.

Konikow, L.F. 1997. "Numerical errors associated with modeling transport and matrix diffusion [abs.]." Eos Trans, AGU 78 (17) : S138.

Konikow, L.F. 1998. February personal communication, email, from L. Konikow to L. Chaturvedi.

Konikow, L.F., D.J. Goode, and G.Z. Hornberger. 1996. A Three-Dimensional Method-of-Characteristics Solute-Transport Model (MOC3D). U.S. Geological Survey, USGS/WRI 96-4267.

Kreitler, C.W., M.S. Akhter, W.F. Mullican III, A.K. Avakian and A.E. Fryar. 1994. Abandoned Well Characterization: A Methodology to Evaluate Regional Hydraulic Controls on Flow from Hydrocarbon Reservoirs into Underground Sources of Drinking Water. Austin, Texas: University of Texas at Austin, Bureau of Economic Geology.

Lambert, S.J. 1987a. Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation. Sandia National Laboratories, SAND86-1054.

Lambert, S.J. 1987b. "Stable-isotope studies of groundwaters in Southeastern New Mexico, SAND85-1978c," in the Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project, ed. by Lokesh Chaturvedi. Santa Fe, NM: Environmental Evaluation Group, EEG-34.

Lambert, S.J. and J.A. Carter. 1987. Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico, I: Principles and Preliminary Results. Sandia National Laboratories, SAND87-0388.

Larson, K.W. 1996. E-mail memo from K. W. Larson to M. E. Lord, P. Vaughn, and M. S. Y. Chu on fracture model ideas.

LaVenue, M. 1991. January 28 Sandia National Laboratories memorandum to distribution on the anomalous Culebra water-level rises near the WIPP site, Sandia National Laboratories Fluid Flow and Transport Division 6344.

Lee, W.W.-L., L. Chaturvedi, M. K. Silva, R. Weiner and R.H. Neill. 1994. An Appraisal of the 1992 Preliminary Performance Assessment for the Waste Isolation Pilot Plant. Albuquerque, NM: Environmental Evaluation Group, EEG-57.

Lenke, L.R., J.W. Berglund and R.A. Cole. 1996. Blowout Experiments Using Fine Grained Silica Sand in an Axisymetric Geometry. Albuquerque, NM: New Mexico Engineering Research Institute, NMERI 1996/7/32250.

Lowenstein, T.K. 1987. Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico. Santa Fe, NM: Environmental Evaluation Group, EEG-36.

Luker, R.S., T.W. Thompson and B.M. Butcher. 1991. "Compaction and permeability of simulated waste," in Rock Mechanics as a Multidisciplinary Science Proceedings of the 32nd U.S. Symposium, edited by J. C. Roegiers. Rotterdam, Netherlands: A. A. Balkema, 693-702.

Lyons, W.C. 1984. Air and Gas Drilling Manual. Houston, TX: Gulf Publishing Company.

McFadden, M.H. 1996. January 2 letter from M. H. McFadden, Assistant Manager, DOE Carlsbad Area Office to Robert H. Neill, Director, Environmental Evaluation Group.

Magruder, J.B., L.H. Stiles and T.D. Yelverton. 1990. "Review of the means San Andres unit CO_2 tertiary project." SPE Journal of Petroleum Technology, (May) : 638-644.

Malik, M.A. 1998. "Compositional simulations of a CO_2 flood in Ford Geraldine Unit, Texas." Paper prepared for presentation at the 1998 SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas. 23-26 March. SPE 39794.

May, B. 1995a. "Livingston Ridge Delaware, field summary," in Symposium of the Oil and Gas Fields of Southeastern New Mexico. Roswell, NM: Roswell Geological Society, 264-266.

May, B. 1995b. "Lost Tank Delaware, field summary," in a Symposium of the Oil and Gas Fields of Southeastern New Mexico. Roswell, NM: Roswell Geological Society, 280-282.

Mercer, J.W. and B.R.Orr. 1979. Interim Data on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site Southeast New Mexico. U.S. Geological Survey, USGS/WRI 79-88.

Monroe, W.W., M.K. Silva, L.L. Larson and F.M. Orr. 1990. "Composition paths in four-component systems: effects of dissolved methane on 1D CO2 flood performance." SPE Reservoir Engineering, (August) : 423-432.

Moritis, G. 1993. "Permian basin operators press CO_2 injection programs." Oil and Gas Journal, (August 16) : 19-23.

Murphy, M.B. 1997. Advanced Oil Recovery Technologies for Improved Recovery from Slope Basin Clastic Reservoirs, Nash Draw Brushy Canyon Pool, Eddy County, New Mexico, Annual Report September 25, 1995 to September 24, 1996. U.S Department of Energy, DOE/BC/14941-6.

National Archives and Records Administration, Office of the Federal Register. 1997. "Nuclear Safety Management, Quality Assurance Requirements." 10 Code of Federal Regulations Part 830.120. Washington, D.C.: U.S. Government Printing Office.

National Research Council, Commission on Geosciences, Environment, and Resources, Board on Radioactive Waste Management, Committee on the Waste Isolation Pilot Plant. 1996. The Waste Isolation Pilot Plant: A Potential Solution for the Disposal of Transuranic Waste. Washington, D. C.: National Academy Press.

Neill, R.H. 1997a. February 7 letter from R. H. Neill, EEG to Frank Marcinowski, EPA on the request for information from the January 21 meeting.

Neill, R.H. 1997b. March 14 letter from R. H. Neill to F. Marcinowski.

Neill, R.H. 1997c. August 29 letter from R. H. Neill, EEG to G. Dials, DOE on June 30 meeting, EPA Docket A-93-02, II-D-117.

Neill, R.H. 1997d. March 14 letter from R. H. Neill, EEG to EPA Docket on WIPP CCA, EPA Docket A-93-02, II-H-25.

Neill, R.H. and J.K. Channell. 1983. Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP. Santa Fe, NM: Environmental Evaluation Group, EEG-24.

Neill, R.H., J.K. Channell, L. Chaturvedi, M.S. Little, K. Rehfeldt and P. Spiegler. 1983. Evaluation of the Suitability of the WIPP Site. Santa Fe, NM: Environmental Evaluation Group, EEG-23.

Neill, R.H., L. Chaturvedi, W. W.-L. Lee, T.M. Clemo, M.K. Silva, J.W. Kenney, W.T. Bartlett and B.A. Walker. 1996. Review of the WIPP Draft Application to Show Compliance with EPA Transuranic Waste Disposal Standards. Albuquerque, NM: Environmental Evaluation Group, EEG-61.

Nigbor, M.T. 1982. State of the Art of Solution Mining for Salt, Potash and Soda Ash. Woodstock, IL: Solution Mining Research Institute, Research Project Report No. 82-0002-SMRI.

Novak, C.F. 1997. April 27 memorandum from C. F. Novak to R. Vann Bynum, "Calculations of actinide solubilities in WIPP SPC and ERDA6 brines under MgO backfill scenarios containing nesquehonite or hydromagnesite as the MgO-CO_2 solubility-limiting phase." Sandia National Laboratories, WPO#46124.

Novak, C.F., H.W. Papenguth, C.C. Crafts and N.J. Dhooge. 1994. Actinide Source Term Paper. Revision 1, November 15. Sandia National Laboratories.

Nuclear Energy Agency, International Atomic Energy Agency. 1997. International Peer Review of the 1996 Performance Assessment of the U.S. Waste Isolation Pilot Plant (WIPP). Issy-les-Moulineaux, France: Organisation for Economic Cooperation and Development.

Östhols, E., J. Bruno and I. Grenthe. 1994. "On the influence of carbonate on mineral dissolution: II. The solubility of microcrystalline ThO_2 in CO_2-H_2O media." Geochim. Cosmochim. Acta 58: 613-623.

Oversby, V.M. 1997. The solubility of plutonium under conditions expected in the WIPP repository. Albuquerque, NM: Environmental Evaluation Group, unpublished.

Peake, T. 1996. Technical memorandum to EPA Docket A-92-56, WIPP-examination of mining and hydraulic conductivity.

Powers, D.W. 1996. "Observations of the effects of water flooding on the Salado Formation. Synopsis and presentation," in Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis, by Matthew K. Silva. Albuquerque, NM: Environmental Evaluation Group, EEG-62, 63-71.

Powers, D.W. and R.M. Holt. 1990. "Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site," in Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Field Trip #14 Guidebook. Geological Society of America 1990 Annual Meeting. Dallas, TX: Dallas Geological Society.

Powers, D.W., S.J. Lambert, S.E. Shaffer, L.R. Hill and W.D. Weart. 1978. Geological Characterization Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. Sandia National Laboratories. SAND78-1596.

Pyrak-Nolte, L.J., L.R. Myer, N.G.W. Cook and P.A. Witherspoon. 1987. "Hydraulic and mechanical properties of natural fractures in low permeability rock," in Proceedings Sixth International Congress on Rock Mechanics, Montreal, Canada, edited by Herget and Vongsaissal. Rotterdam, Netherlands: A.A. Balkema.

Rai, D., A. Felmy, D.A. Moore and M.J. Mason. 1995. "The solubility of Th(IV) and U(IV) hydrous oxides in concentrated $NaHCO_3$ and Na_2CO_3 solutions," in Scientific Basis for Nuclear Waste Management XVIII; Symposium held October 23-27, 1994, Kyoto, Japan, ed. T. Murakami and R. C. Ewing. Pittsburgh, PA: Materials Research Society, 1143-1150.

Ramey, D. 1985. Chemistry of the Rustler Fluids. Santa Fe, NM: Environmental Evaluation Group, EEG-31.

Ramey, J.D. 1976. May 5 memorandum from J. D. Ramey, Director, New Mexico Oil Conservation Division to John F. O'Leary on waterflows in and near waterflood projects in Lea County.

Ramey, J.D. 1977. August 2 New Mexico Oil Conservation Commission Administrative Order Approving Application of Texaco, Inc. to expand its Rhodes "B" Federal Water Flood Project in the Rhodes Pool in Lea County, New Mexico, Order WFX No. 454.

Ramey, J.D. 1995. "Regulation pertaining to oil and gas drilling," in Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Carlsbad, NM: Westinghouse Electric Corporation, Waste Isolation Division, vol. 3, chap. IX.

Ramsey, J., M. Wallace and H.-N. Jow. 1996 Analysis Package for the Culebra Flow and Transport Calculations (Task 3) of the Performance Assessment Analyses Supporting the Compliance Certification Application, Analysis lan 019, Version 00, December 11. Sandia National Laboratories, WPO#40516.

Rao, L.F. 1996. December 18 letter from L. F. Rao, PNNL/Battelle to W. W.-L. Lee, EEG answering Lee's December 2, 1996.

Raven, K. and J. Gale. 1985. "Water flow in a natural fracture is a function of stress and sample size." Journal of Rock Mechanics and Mineral Science Abstracts 22 (4): 251-261.

Rayrock Yellowknife Resource Inc. 1996. Annual Report.

Reed, D.T., S. Okajima, and M.K. Richmann. 1994. "Stability of plutonium (VI) in selected WIPP brines." Radiochemica Acta 66/67: 105-111.

Reed, D.T., D.G. Wygmans and M.K. Richmann. 1996. Actinide Stability/Solubility in Simulated WIPP Brines Project: Stability of Pu(VI), Np(VI), and U(VI) in simulated WIPP Brine. Interim Report. Argonne, IL: Argonne National Laboratory.

Rucker, D.F. 1998. Sensitivity Analysis of Performance Parameters Used in Modeling the Waste Isolation Pilot Plant. Albuquerque, NM: Environmental Evaluation Group, to be published as EEG-69.

Sandia National Laboratories. 1982. Basic Data Report for drillhole WIPP 12 (Waste Isolation Pilot Plant - WIPP). Sandia National Laboratories, SAND82-2336.

Sandia National Laboratories. 1989. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. Sandia National Laboratories, SAND89-0462.

Sandia National Laboratories. 1990. Preliminary comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND90-2347.

Sandia National Laboratories. 1991. Preliminary comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND91-0893/1-3.

Sandia National Laboratories. 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND92-0700/1-5.

Sandia National Laboratories. 1997. Chemical Conditions Model: Results of the MgO Backfill Efficacy Investigation. EPA Docket A-93-02, II-A-39.

Searls, J.P. 1997. "Potash 1996." Engineering & Mining Journal 198 (April): 36-38.

Searls, J.P. 1996. "Potash." Engineering & Mining Journal 197 (March): 64-68.

Searls, J.P. 1995. "Potash." Engineering & Mining Journal 196 (March): 76-77.

Sewards, T. 1991. Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation. Sandia National Laboratories, SAND90-7019.

Sewards, T., R. Glenn and K. Kiel. 1991a. Mineralogy of the Rustler Formation in the WIPP-19 Core. Sandia National Laboratories, SAND87-7036.

Sewards, T., M.L. Williams and K. Kiel. 1991b. Mineralogy of the Culebra Dolomite Member of the Rustler Formation. Sandia National Laboratories, SAND90-7008.

Sewards, T., A. Brearly, R. Glenn, I.D.B. Mackinnon and M.D. Siegel. 1992. Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the WIPP in Southeastern New Mexico. Sandia National Laboratories, SAND90-2569.

Shatz, J.F. 1997. Waste Spallings Calculations, technical report. Del Mar, CA: John F. Shatz Research & Consulting, Inc.

Shock, D. 1985. "Solution mining of soluble salts - its scope and its future," in Salts & Brines '85: Proceedings of the Symposium Solution Mining of Salts and Brines, New York, New York, February 25-26, 1985, ed. W. J. Schlitt. New York, NY: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

Shock, D.A. and J.G. Davis. 1970. "Solution mining test sites - Carlsbad Basin, New Mexico," in Third Symposium on Salt. Cleveland, OH: Northern Ohio Geologic Survey, Inc., 433-438.

Siegel, M.D., S.J. Lambert and K.L. Robinson, ed. 1991. Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. Sandia National Laboratories, SAND88-0196.

Silva, M.K. 1994. Implications of the Presence of Petroleum Resources on the Integrity of the WIPP. Albuquerque, NM: Environmental Evaluation Group, EEG-55.

Silva, M.K. 1996. Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis. Albuquerque, NM: Environmental Evaluation Group, EEG-62.

Silva, M.K. and F.M. Orr. 1987. "Effect of oil composition on minimum miscibility pressure - part 1: solubility of hydrocarbons in dense CO_2." SPE Reservoir Engineering, (November) : 468-478.

Simpson, H.J., A.L. Herczeg, R.F. Anderson, R.M. Trier, G.G. Mathieu and B.L. Deck. 1985. Mobility of Radionuclide in High Chloride Environments. U.S. Nuclear Regulatory Commission, NUREG/CR-4237.

Smil, V. 1997. "Global population and the nitrogen cycle." Scientific American, (July) , 76-81.

Smith, R.C. 1990. "Conversion of a flooded potash mine to solution mining." Phosphorus & Potassium, no. 168 (July-August) : 23-28.

Snyder, R.P. 1985. Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. U.S. Geological Survey, USGS-OFR-85-229.

Stalkup, F.I. 1983. Miscible Displacement. New York, NY: Society of Petroleum Engineers of AIME.

Stoelzel, D.M. and D.G. O'Brien. 1996. The Effects of Saltwater Disposal and Waterflooding on WIPP. Sandia National Laboratories, WPO#40837.

Stoelzel, D.M. and P.N. Swift. 1997. Supplementary Analyses of the Effects of Saltwater Disposal and Waterflooding on WIPP. Sandia National Laboratories.

Taber, J.J., F.D. Martin and R.S. Seright. 1997a. "EOR screening criteria revisited - part 1: introduction to screening criteria and enhanced recovery field projects." SPE Reservoir Engineering, (August) : 189-198.

Taber, J.J., F.D. Martin and R.S. Seright. 1997b. "EOR screening criteria revisited - part 2: applications and impact of oil prices." SPE Reservoir Engineering, (August) : 199-205.

Telander, M. R. and R. E. Westerman. 1996. Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments. Sandia National Laboratories, SAND96-2538.

Terzaghi, K. and B. Peck. 1948. Soil Mechanics in Engineering Practice. New York, NY: John Wiley & Sons, Inc.

Thrash, J.C. 1979. "Twofreds Field - tertiary oil recovery project," presented at the 1979 SPE Annual Technical Conference and Exhibition, September 23-26. SPE Paper 8382.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. Expert Judgement on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant. Sandia National Laboratories, SAND92-1382.

Trovato, R. 1996. August 14 letter with attachment from Director, EPA, Office of Radiation and Indoor Air to George Dials, Manager, DOE Carlsbad Area Office.

Uhland, D.W. and W.S. Randall. 1986. 1986 Annual Water Quality Data Report for the Waste Isolation Pilot Plant. U.S. Department of Energy, DOE/WIPP-86-006.

Uhland, D.W., W.S. Randall and R.C. Carrasco. 1987. 1987 Annual Water Quality Data Report for the Waste Isolation Pilot Plant. U.S. Department of Energy, DOE/WIPP-87-006.

U.S. Congress. 1996. The Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579, October 30, 1992, as amended by Public Law 104-201, September 23.

U.S. Department of Energy. 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026

U.S. Department of Energy, Albuquerque Operations Office. 1984. Design Criteria: Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-II. WIPP/DOE-071.

U.S. Department of Energy. 1991. Quality Assurance. DOE Order 5700.6C.

U.S. Department of Energy. 1993. Test Phase Plan for the Waste Isolation Pilot Plant. DOE/WIPP/89-011, Revision 1.

U.S. Department of Energy, Carlsbad Area Office. 1994. TRU Waste Characterization Quality Assurance Program Plan, draft. DOE/WIPP/CAO-94-1010.

U.S. Department of Energy, Carlsbad Area Office. 1995a. Transuranic Waste Characterization Quality Assurance Program Plan. DOE/CAO-94-1010.

U.S. Department of Energy, Office of Environmental Management. 1995b. Closing the Circle on the Splitting of the Atom. DOE/EM-0266.

U.S. Department of Energy. 1995c. Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant. Draft-DOE/CAO-2056.

U.S. Department of Energy, Carlsbad Area Office. 1996a. National Transuranic Waste Management Plan. DOE/NTP-96-1204, Revision 0.

U.S. Department of Energy, Carlsbad Area Office. 1996b. Quality Assurance Program Document. DOE/CAO-94-1012, Revision 1 and Revision 0, 1994.

U.S. Department of Energy, Carlsbad Area Office. 1996c. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant. Final. DOE/CAO-1996-2184 (21 vols.).

U.S. Department of Energy. 1996d. Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement, draft supplement. DOE/EIS-0026-S-2.

U.S. Department of Energy, Carlsbad Area Office. 1997a. Expert Elicitation on WIPP Waste Particle Size Distribution(s) During the 10,000 Year Regulatory Post-Closure Period. Final Report.

U.S. Department of Energy. 1997b. Geotechnical Analysis Report for July 1995 - June 1996. DOE/WIPP-97-2261.

U.S. Department of Energy, Carlsbad Area Office. 1997c. National TRU Waste Management Plan. DOE/NTP.-96-1204, Rev. 1.

U.S. Department of Energy, Carlsbad Area Office. 1997d. Injection Methods: Current Practices and Failure Rates in the Delaware Basin. DOE/WIPP-97-2240.

U.S. Department of Energy. 1998. Current Drilling Practice in the Vicinity of WIPP. DOE/WIPP-98-2597.

U.S. Environmental Protection Agency. 1985. Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register (September 19) vol. 50, no. 182, pp. 38066-38088.

U.S. Environmental Protection Agency. 1993. Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. 40 Code of Federal Regulations Part 191.

U.S. Environmental Protection Agency. 1996. Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register (February 9) vol. 61, no. 28, pp. 5224-5245.

U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. 1996a. Compliance Application Guidance for 40 CFR Part 194. EPA 402-R-95-014.

U.S. Environmental Protection Agency. 1997a. Audit of the Parameter Traceability and Qualification of Existing Data, Docket A-93-02, II-A-48.

U.S. Environmental Protection Agency. 1997b. Compliance Application Review documents for the Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Proposed Certification Decision. EPA 402-R-97-013.

U.S. Environmental Protection Agency. 1997c. Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Certification Decision; Proposed Rule. Federal Register (October 30) vol. 62, no. 210, pp. 58792-58838.

U.S. Environmental Protection Agency. 1997d. 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.

U.S. Environmental Protection Agency. 1997e. Technical Support Document for Section 194.23: Spallings Evaluation, EPA Docket A-93-02, III-B-10.

U.S. Environmental Protection Agency. 1997f. Technical Support Document for Section 194.23: Spallings Evaluation, EPA Docket A-93-02, III-B-11.

U.S. Environmental Protection Agency. 1997g. Technical Support Document for Section 194.14: Content of Compliance Certification Application, EPA Docket A-93-02, III-B-3.

U.S. Environmental Protection Agency. 1997h. Technical Support Document for Section 194.32: Fluid Injection Analysis, EPA Docket A-93-02, III-B-22.

U.S. Environmental Protection Agency. 1997i. Technical Support Document for Section 194.55: Compliance Assessment Statistics, EPA Docket A-93-02, III-B-26.

U.S. Environmental Protection Agency. 1997j. Technical Support Document for Section 194.14: Assessment of K_ds Used in CCA, EPA Docket A-93-02, III-B-4.

U.S. Environmental Protection Agency. 1997k. Technical Support Document for Section 194.194.51, 194.52, and 194.55: Dose Validation Evaluation, EPA Docket A-93-02, III-B-25.

U.S. Environmental Protection Agency. 1997l. Technical Support Document for Section 194.23: Models and Computer Codes, EPA Docket A-93-02, III-B-6.

U.S. Environmental Protection Agency. 1997m. Technical Support Document for Section 194.23: Parameter Justification Report, EPA Docket A-93-02, III-B-14.

U.S. Environmental Protection Agency. 1998. EPA's Analysis of Air Drilling at the WIPP. EPA Docket A-93-02, IV-A-1.

U.S. General Accounting Office. 1989. Drinking water standards are not preventing contamination from injected oil and gas wastes: U.S. General Accounting Office, Resources, Community, and Economic Development Division. Washington, D.C.: Government Printing Office, GAO/RCED-89-97.

Van Kirk, C.W. 1994. September 16 report concerning salt water blow-out January 1991 on the "Bates Lease" Sections 10 and 15, Township 26 South, Range 37 East, NMPM, Lea County, New Mexico.

Wallace, M.G., R. Beauheim, C. Stockman, M.A. Martell, K. Brinster, R. Wilmot and T. Corbet. 1995. FEPs Screening Analysis, NS-1: Dewey Lake Data Collection and Compilation. Sandia National Laboratories. WPO#30650.

Wang, Y. and L. Brush. 1996. January 26 memorandum from Y. Wang and L. Brush to M. Tierny, "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment." Sandia National Laboratories, WPO#31943.

Wash, R. 1982. "Twofreds saved by CO_2 flood." Drill Bit, (July) : 52-55.

Wawersik, W.R., L.W. Carlson, J.A. Henfling, D.J. Borns, R.L. Beauhiem, C.L. Howard and R.M. Roberts. 1997. Hydraulic Fracturing Tests in Anhydrite Interbeds in the WIPP, Marker Beds 139 and 140. Sandia National Laboratories, SAND95-0596.

Weart, W.D. 1993. December 1 letter from W.D. Weart, Sandia National Laboratories WIPP Scientific Programs Manager to Mark W. Frei, Director of U.S. Department of Energy, Office of Waste Management Project.

Weiner, R.F., D.E. Hobart, C.D. Tait and D.L. Clark. 1996. Sandia National Laboratories. Waste Isolation Pilot Plant. Analysis of Actinide Oxidation States in the WIPP. Sandia National Laboratories, WPO#35194.

Westinghouse Electric Corporation. 1988. Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant. U.S. Department of Energy, DOE/WIPP-88-025.

Westinghouse Electric Corporation, Waste Isolation Division. 1994. Waste Isolation Pilot Plant Environmental Monitoring Plan. U.S. Department of Energy, DOE/WIPP-94-024.

Westinghouse Electric Corporation, Waste Isolation Division. 1995. WIPP Annual Site Environmental Report for Calendar Year 1994. Westinghouse Electric Corporation, DOE/WIPP-95-024.

Westinghouse Electric Corporation, Waste Isolation Division. 1996. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1995. U.S. Department of Energy, DOE/WIPP-96-2182.

Westinghouse Electric Corporation, Waste Isolation Division. 1997. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1996. U.S. Department of Energy, DOE/WIPP-97-2225.

White, D. 1995. "Los Medanos Delaware, field summary," in Symposium of the Oil and Gas Fields of Southeastern New Mexico. Roswell, NM: Roswell Geological Society, 275-277.

Wilson, C., D. Porter, J. Gibbons, E. Oswald, G. Sjoblom and F. Caporuscio. 1997. Final Report Waste Isolation Pilot Plant Conceptual Models Third Supplementary Peer Review Report. Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

Zheng, L., C. Xuehua and T. Mingshu. 1991. "MgO-type delayed expansive cement." Cement and Concrete Research 21 (6) : 1049-1057.

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

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003
FAX (505) 828-1062

February 7, 1997

Mr. Frank Marcinowski, Director
Center for the Waste Isolation Pilot Program
U.S. Environmental protection Agency
Office of Radiation and Indoor Air
401 M Street SW
Washington, DC 20460

Dear Mr. Marcinowski:

At our January 21, 1997 meeting, you requested our comments on the WIPP Compliance Certification Application (CCA) now, because the end of the 120 day comment period on March 17 may be too late for you to seriously consider our comments in your deliberations on the CCA. We are therefore submitting our partial comments on the CCA at this time for your consideration.

The EEG has identified many specific issues in its evaluation of the WIPP-CCA. These issues can be grouped in the following broad categories:

- Lack of sufficient justification in disqualifying several features, events, and processes (FEPS) from consideration.
- Insufficient basis for selecting certain conceptual models and rejecting others.
- Incorrect estimation of probabilities of certain events.
- Insufficient justification or erroneous assumptions in assigning values for several input parameters.

The EEG has attended most of the meetings of the WIPP/CCA Peer Review Panels that were organized as required by 40 CFR 194.27. 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.

In reviewing the CCA, the EEG does not accept the arguments of "no consequence" to delete the otherwise plausible features, events and processes, and to justify incorrect values for certain input parameters. Such arguments, made on the basis of piecemeal, limited sensitivity analyses, may be misleading in projecting the relative importance of scenarios, conceptual models and input parameters for CCDF calculations. We strongly recommend that the EPA reject all such "no consequence" arguments and demand that a fresh set of calculations be performed after the EPA has examined the robustness of all the CCA assumptions regarding FEPs, conceptual models, numerical models, probability assignments, and input parameter values, and has provided alternative models and numbers to the DOE. This comment also applies to the recommendations of the peer review groups. The Conceptual Model Peer Review Group, for example, provides solid technical arguments for not accepting certain conceptual models advocated and used in the CCA, but then has found them acceptable on "no consequence" basis without providing sufficient explanation for such acceptance.

Comments on specific issues are enclosed. These are arranged as brief papers that can be read as stand-alone documents. We plan to submit additional comments to you in this format, as they are developed in the next few weeks.

Sincerely,

Robert H. Neill
Director

RHN:LC:js
Enclosures: EEG Reviews of the WIPP-CCA,
Plutonium Solubility
Chemical Retardation
Spallings Model
Fluid Injection
Brine Reservoir Assumptions
Engineered Barriers

cc: Ms. Jennifer Salisbury, NMEMNRD
Mr. Lindsay Lovejoy, Jr., NMAG
EPA docket for WIPP (A-9302)

Environmental Evaluation Group Review of the WIPP-CCA, 2/7/97

CHEMICAL RETARDATION VALUES FOR THE CULEBRA

In the event of a borehole intrusion, the Culebra Aquifer, which lies 400 meters above the WIPP horizon, is one possible groundwater pathway for release of radionuclides to the accessible environment. Chemical retardation is expected to slow the transport of radionuclides through the fractured dolomite of the Culebra Aquifer. However, the DOE application has used values for estimating retardation coefficients that appear to lack justification.

Faced with a lack of field data and limited column test data for WIPP, the DOE CCA used retardation values from crushed rock samples in the laboratory to represent field conditions. Justification by the DOE is based on the following observations.

1) Sorption can occur in pores of various scales.

2) The surface area to volume ratio in crushed rocks sorption tests are similar to in-situ Culebra dolomite.

3) For long flow paths and long flow times radionuclides have sufficient time to diffuse into these pore spaces and sorb.

While EEG agrees that there appears to be a reasonable theoretical basis for using crushed rock, the EEG disagrees with the final data used in the CCA. Empirical sorption tests were done for all permutations of four types of brine; CO_2 levels of 0.033%, 0.24%, 1.4%, or 4.1%; and no, low, intermediate or high levels of organics. Because DOE plans to add M_gO as backfill, the fugacity of CO_2 in the repository is expected to be 10^{-7}. Thus, EEG discarded the results for CO_2 levels of 0.24%, 1.4%, and 4.1%. EEG also discarded results that did not meet DOE's own quality control criteria, and the results from a set of mechanistic sorption experiments because the dolomite was not from the Culebra. The average of the batch results formed the upper end of a uniform distribution.

Results from flow-through experiments using rock cores formed the lower end of the uniform distribution. In some cases, there was no radionuclide breakthrough at 300 days, so a minimum estimated K_d, assuming breakthrough at 300 days was used.

The DOE did not include the influence of organics on K_d values. In batch tests, even low concentrations of organics dramatically reduced K_d values. The impact of organics are included in the Kd values recommended by EEG.

The following tables show the Kd values used in the CCA, and the values suggested by the EEG using the criteria described above.

Table 1. K_ds used by DOE in CCA.

Oxidation State	Am	Pu	U	Th	Np
III	20 - 500	20 - 500			
IV		900 - 20000	900 - 20000	900 - 20000	900 - 20000
V					1 - 200
VI			0.03 - 30		

Table 2. K_ds recommended by EEG.

Oxidation State III, IV, V, VI	Am	Pu	U	Th	Np
	73 - 314	83 - 270	0.35 - 5	0.15 - 1.5	1.0 - 21

PLUTONIUM SOLUBILITY-EXPERIMENTAL MEASUREMENTS VERSUS CCA CALCULATED VALUES

Where brine has dissolved waste in the repository, direct drilling provides a vertical pathway for the long-lived actinides to return to the environment. Plutonium constitutes 87% of the initial radioactivity in the performance assessment calculations. Oxidation state is a factor that has an impact on the plutonium solubility. The DOE CCA assumes that the plutonium in the repository will be either at Pu(III) or Pu(IV), with 50% probability of one or the other. However, the solubilities are not measured for Pu(III) or Pu(IV). Rather, the solubility of Pu(III) is calculated using thermodynamic data for Nd(III) and the solubility of Pu(IV) is calculated using thermodynamic data for Th(IV).

While solubility experiments show that regardless of the initial oxidation state, Pu (VI) dominates at steady state conditions, it is not included in the performance assessment calculations. Pu(VI) has a high solubility in the conditions anticipated for the WIPP repository by the CCA.

The magnesium oxide backfill is anticipated to keep the repository at a pH of 10 and reducing. Reed et al. (1996) reported, that for brine at pH of 8 to 10, and reducing conditions, Pu(VI) is stable with an apparent solubility of 10^{-4} M. While it has been argued that corrosion of the steel drums would result in a reducing environment, Rao (1996) found that it was not possible to reduce Pu(VI) below Pu(V) despite adding more iron per unit mass of plutonium than could be expected in the repository, even assuming complete dissolution of the steel containers. Clark and Tait (1995) also concluded that Pu (VI) is stable in WIPP brines. Table 1. compares the calculated values used in the CCA and the measured values reflective of conditions anticipated in the repository.

Table 1. Solubility of plutonium as determined by calculations and experiments

Source of Brine	CCA calculations	Experiment, Reed et al.
Castile	5.7×10^{-9} M	8×10^{-5} M
Salado	4.4×10^{-6} M	9×10^{-5} M

The experimental evidence leads to the following conclusions:

1) Pu(VI) will be stable in the WIPP repository.

2) There is no support for the assumption that plutonium will stabilize in either oxidation state Pu(III) or Pu(IV).

3) The calculated results used in the DOE CCA are significantly different from experimental results for WIPP brines under anticipated repository conditions.

The EEG therefore recommends using the experimental values determined by Reed et al. (1996) shown in Table 1, for the CCA calculations.

References

1. D. L. Clark and C. D. Tait, 1995. LANL Progress Report. December 12, 1995. CCA Additional References No. 134.

2. L. F. Rao, 1996. PNNL Progress Report, April 1, 1996.

3. D. T. Reed, D. G. Wygmans, M. K. Richmann, 1996. "Stability of Pu(VI), Np(VI), and U(VI) in Simulated WIPP Brine," ANL Interim Report, CCA Additional References No. 539.

SPALLINGS MODEL

1. Critique of the Model Used in the CCA

For the purposes of the WIPP Compliance Certification Application (CCA) calculations, spallings refers to the entrainment of solid waste during the venting of high pressure gas from the repository in the event of a drilling intrusion. Spallings will occur when the roof of a waste room is penetrated by a drill, if the pressure in the room is sufficient to overcome the hydrostatic pressure of the drilling mud, about 8 MPa. Visual inspection of gas pressures calculated by the BRAGFLO code[1] indicates that over 80% of the undisturbed repository calculations predict pressures over 8 MPa after 10,000 years, with roughly 25-30% reaching this level in less than 1,000 years. The highest pressure calculated was nearly 16 MPa. The CCA calculations predict spallings to be a very important release mechanism. Spallings contributes to over 50% of the release estimates for human intrusion and was the largest form of release in over 10% of the calculated histories. The largest calculated release was less than, but within a factor of five, of the EPA normalized release limit for the 10% probability level.

The EEG finds the spallings model as used in the CCA to be inappropriate on three counts; 1) exclusion of brine from the spallings scenario, 2) the conceptual model of the spallings process, and 3) the experimental basis of the model validation. The spallings model is defined as gas driven entrainment of solid particles. The effect of brine in the waste panel is ignored. Brine may effect the spallings process in three ways. Capillary forces from low saturation may provide a binding force that inhibits spall which is conservatively ignored. Brine may also increase the effective driving force of the spall process increasing the amount of spall. In addition, the brine would contain radionuclides in solution. The CCA does include brine release from the penetration of the repository as a separate, longer term, two-phase flow calculation using repository conditions that are unmodified by the spall process. The spallings model should include the effects of brine.

For the spallings calculations, waste is assumed to be composed of uniform sized granules held together by a cohesive strength of 1 psi (0.007 MPa). The grain size is a sampled parameter in the CCA analysis. 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 releases from a heterogeneous medium.

Spalling can be viewed as a two step process. First, the explosive depressurization of the waste near the drill puncture, lasting a few seconds, followed by the erosion of channels through the waste by gas further from the puncture location, lasting hundreds of seconds. However, the spallings model includes only the second process. Two justifications are presented for ignoring the first process: 1) The pressure drop increase resulting from ejecting the drilling mud from the drill string is a relatively slow process, 2) the erosion process will proceed to a stable void configuration independent of the initial entrainment. In other words, a larger initial spall will be followed by less erosion than a smaller initial spall, resulting in the same final void ratio. 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 the pressure differential needed 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.

The spallings model was validated by DOE using a set of bench scale experiments. A four inch high cylindrical cavity of 20 inches in diameter was supplied with high pressure gas through a plenum around the circumference. A vent of variable diameter was placed in the center of the top of the cylinder. The cylinder was filled with silica sand. The experiments were run by stepping the pressure maintained at the plenum. The pressure was held constant until no more material was entrained, then stepped to a higher value. These essentially steady state experiments do not encompass the highly transient spallings phenomena. 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. The inclusion of cohesive strength in the spallings model reduces the calculated spall mass by as much as two orders of magnitude. The attached figure shows the sensitivity of the model to waste strength assumptions. The figure presents plots of mass removed by spallings as a function of sampled particle diameter. Each plot represents the mass removed for an assumed waste strength. The waste strength is varied from 0 to 2 psi.

The experiments indicated increasing spall with increasing diameter of the vent. 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[2].

In their initial review, the conceptual model peer review panel deemed the spallings model to be inadequate.[3] Subsequently, the DOE has reconvened the peer review panel twice to reassess the spallings model among others. The DOE presented additional information intended to demonstrate both the validity of the spallings model and the conservatism of the calculations. The peer review panel still considers both the model and the case for conservatism to be inadequate[4,5].

The EEG therefore recommends that further development of the spallings model be pursued. The spallings model should be validated by a set of experiments that adequately simulate the expected processes of spalling in the event of human intrusion into the waste repository. These experiments should include:

a) the effects of varying the brine saturation
b) investigation of the effects of heterogeneity
c) both the rapid depressurization and longer term erosion through channels
d) the effects of varying the waste strength

e) investigation of scale influences

2. Exclusion of Two Processes from the Spallings Model

Two potentially important processes, viz., the "gas erosion" and the "stuck pipe", considered by the DOE in earlier performance assessments[6], have been excluded from the CCA spallings model. These may occur if the gas flows into the drilling mud because the pressure in the repository exceeds the hydrostatic pressure of the drilling mud but the flow rate is insufficient to expel the mud from the drill string. These two phenomena could cause releases that are over an order of magnitude larger than the largest releases calculated in the CCA.

Waste permeability has a strong influence on the gas flow rate through the waste. At lower flow rates, the drilling mud may be able to wash the spall material from the drilling cavity. This is termed gas erosion. In the SPM-2 report[6], releases from 44 to 356 m^3 were considered possible from gas erosion. Compare this to the maximum calculated release of 4 m^3 in the CCA calculations[7]. If the amount of spall is above the carrying capacity of the drilling mud, then the spall will press against the drilling string, slowing the rotation of the drill bit. The normal response of a drilling crew in such circumstances is to raise and then lower the bit in order to clean out the cavity. In the SPM-2 report[6], releases from 43 to 238 m^3 were considered possible from stuck pipe type spall.

Gas erosion and stuck pipe have been excluded from the spallings model because the waste permeability assumptions of the CCA calculations are above the threshold for ejection of the drilling mud from the drill string. The SPM-2 report[6] assumed 10^{-16} m^2 to be the threshold permeability. However, this threshold is not well defined. It certainly is related to the pressure in the repository.

The CCA (Chapter 6, p. 6-100) states that simulated waste compacted under a lithostatic load yielded waste permeability in the range of 10^{-12} m^2 to 10^{-16} m^2. The CCA assigns the waste permeability as a constant at 1.7×10^{-13} m^2, as "representative of the average value of compacted waste." There is no indication that the effects of neglecting the permeability uncertainty on the CCA spallings model were considered[8].

The permeability of the waste is a critical parameter in determining the plausibility of these processes occurring. The value of the permeability should therefore be carefully chosen to reflect, as accurately as possible, the future conditions in the repository. If the potential cementation of the waste by magnesium chloride cement and salt precipitates is considered, the waste permeability may be even lower than the 10^{-16} m^2 lower band assumed in the SPM-2 report[6].

The Engineered Systems Peer Review Panel did not consider these processes or the validity of their deletion from the spallings model. They considered the waste permeability to be adequately determined for the BRAGFLO calculations, but did not consider its potential effect on these processes, or the effect of MgO backfill in reducing waste permeability.

The EEG recommends that a more realistic value or a range of values should be assumed for the waste permeability parameter and potential for the "gas erosion" and the "stuck pipe" processes be included in the spallings scenario with a better defined permeability-pressure threshold.

References

1. Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, SAND96-2226, Figure 2.3.1, December 1996.

2. L.R. Lenke, J.W. Berglund, and R.A. Cole, Blowout Experiments Using Fine Grained Silica Sand in an Axisymetric Geometry, NMERI 1996/7/32250 - Draft, March 1996.

3. C. Wilson, D. Porter, J. Gibbons, E. Oswald, G. Sjoblom, and F. Caporuscio, Conceptual Model Peer Review Report, DOE, July 1996.

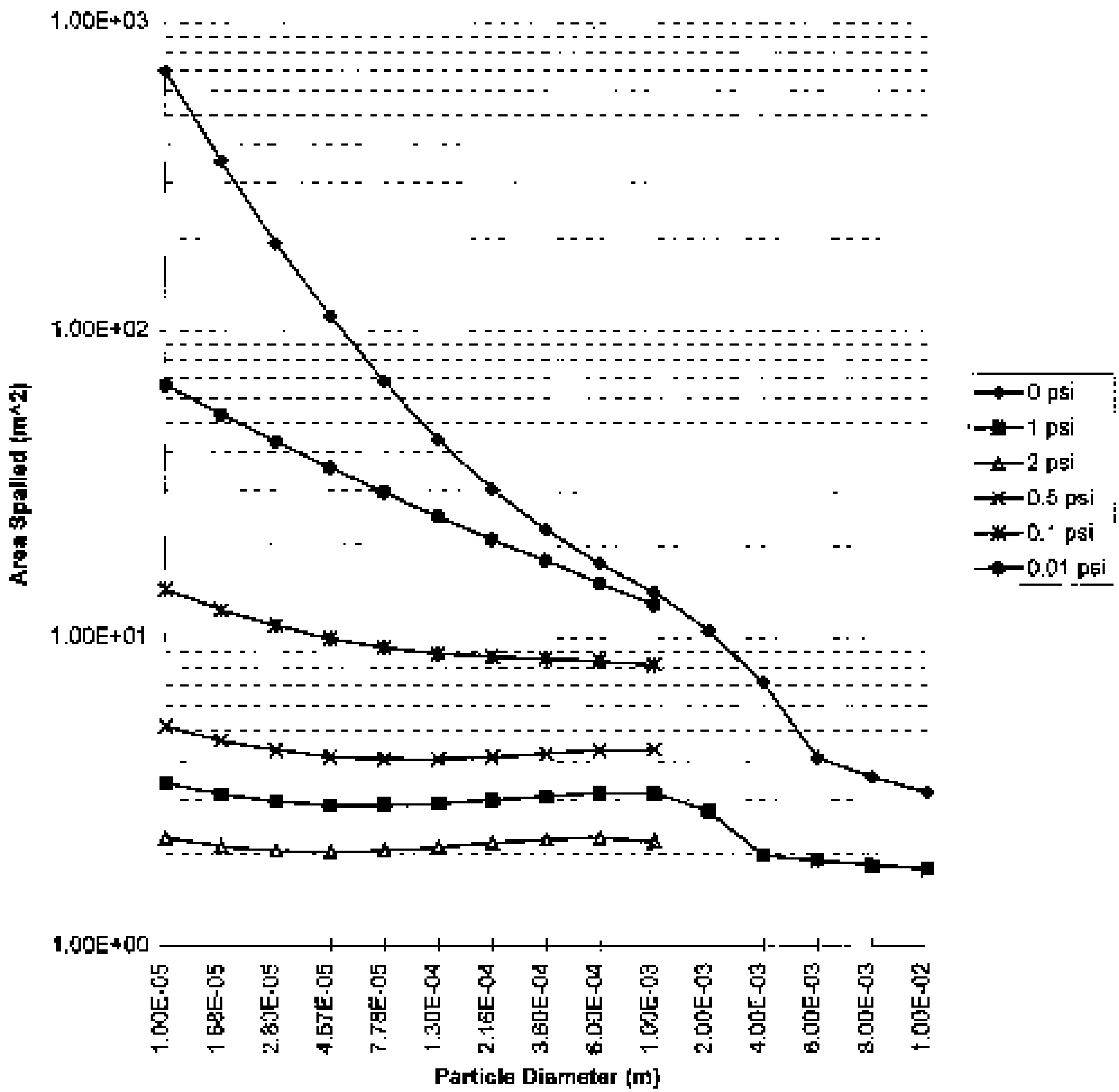
4. C. Wilson, D. Porter, J. Gibbons, E. Oswald, G. Sjoblom, and F. Caporuscio, Supplementary Conceptual Models Peer Review Report, DOE, December 1996.

5. C. Wilson, D. Porter, J. Gibbons, E. Oswald, G. Sjoblom, and F. Caporuscio, Conceptual Models Second Supplementary Peer Review Report, January 1997.

6. B.M. Butcher, S.W. Webb, J.W. Berglund and P.R. Johnson, Systems Prioritization Method — Iteration 2 Baseline Position Paper: Disposal Room and Cuttings Models, Volume 1, March, 1995.

7. J. Helton, Memo: Preliminary Summary of Uncertainty and Sensitivity Analysis Results in Support of the 1996 Compliance Certification Application for the Waste isolation Pilot Plant, December 23, 1996.

8. Form 464 for cuttings waste permeability, WPO 37102, Nov. 28, 1995, and referenced source B.M. Butcher memo to M.S. Tierney, QAP 9-2 Documentation of the Overall Waste Permeability and Flow Property Values for the CCA, January 29, 1996.



Spall area as a function of particle diameter and cementation strength
(Unpublished EEG Calculations Using CUTTINGS_S; Version PA96)

BRINE RESERVOIR ASSUMPTIONS IN THE CCA

The EEG sees no justification for assuming only 8% probability of intercepting a pressurized brine reservoir in the Castile Formation 250 meters below the repository. The fatal flow in the CCA argument for 8% is the assumption that the oil and gas wells that did not report encountering brine did in fact not encounter a brine reservoir. The fact is that the drillers are not required to report brine encounters to the state or federal authorities and no mention would be found in the records unless undue delays or hazardous conditions are encountered.

The 8% probability also ignores the data from WIPP-12 and the TDEM survey over the repository. The borehole WIPP-12 is located north of the repository within the WIPP site. It was drilled to the bottom of the Salado Formation in 1978 and deepened in 1981 at the EEG's suggestion. The DOE contractor (Popielak et al., WIPP-TME-3153, 1983) estimated the volume of the reservoir to be 2.7 million m^3 (17 million barrels). For the maximum possible reservoir thickness of 24 meters, the surface footprint of a cylinder containing this volume would have a diameter of more than 3 km. As the attached figure shows, the WIPP repository is most likely underlain by the brine reservoir encountered by WIPP-12. In addition, the TDEM survey (SAND 87-7144) gives an indication of the presence of brine at the upper Castile horizon. To try to assign specific areas of the presence of brine from this geophysical survey would be over-interpretation of the geophysical data. Combination of the WIPP-12 data and the results of the TDEM survey indicate the existence of brine under the repository. Any borehole drilled into Castile under the repository should therefore be assumed to encounter brine.

The EEG does not find the CCA reservoir volume assumption of 32,000 to 160,000 m^3 to be justified. This is based on the assumption of depletion of reservoirs by future drillers - 100% probability of encounter for the depletion assumption, while only 8% for releases!

The attached table shows the comparison between the characteristics of the WIPP-12 brine reservoir and the CCA assumptions.

The WIPP site was moved twice; in 1975 after the borehole ERDA-6 encountered a brine reservoir, and again in 1982, after WIPP-12 encountered brine. The CCA assumptions of probability should be realistically based on the site specific information, and the characteristics should be based on the WIPP-12 experience.

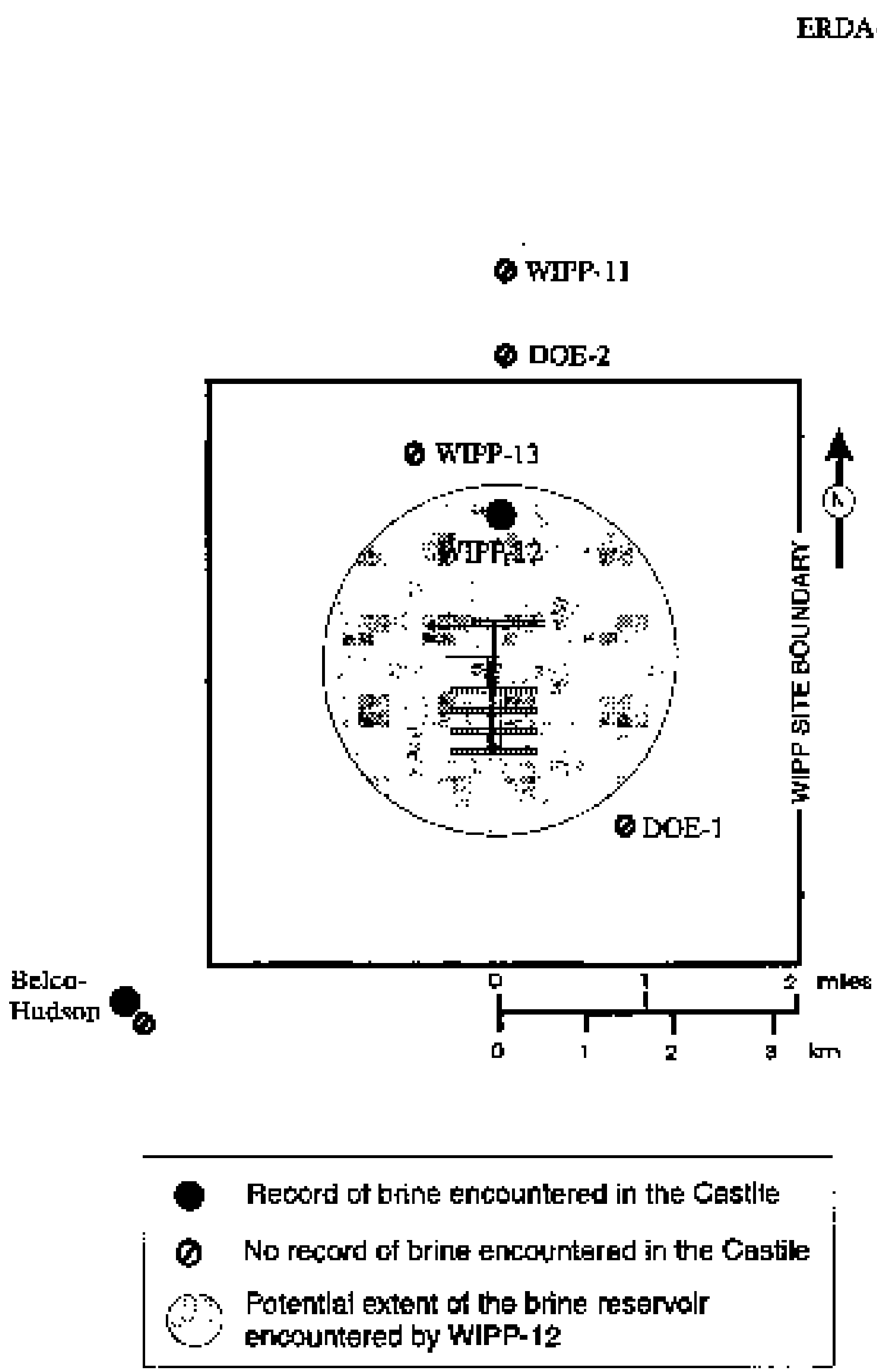
The DOE Conceptual Model Peer Review Panel, in their December 1996 report, essentially agrees with the EEG position, but has accepted the DOE position that there is no significant consequences of the probability and volume assumptions.

The EEG does not accept the "no consequence" argument that is based on piecemeal, partial sensitivity analyses.

Comparison of WIPP-12 Brine Reservoir and the CCA Assumptions

Parameter	WIPP-12 (m^3)	CCA (m^3)
Total Reservoir Volume	2.7×10^6 (a)	32,000 to 160,000 (d)
Projected Max. Artesian Flow	55,821 (b)	5,200 (e)
Flow to Surface During Drilling	4,306 (c)	400 to 2,100 (f)

(a) WIPP/TME-3153, p. H-54
(b) WIPP/TME-3153, p. H-55
(c) WIPP/TME-3153, p. H-9; Actual "unavoidable" flow
(d) DOE/CAO-1996-2184, Table 6-26
(e) CMPRR-Suppl., 12/1996, p. 42; To the Culebra, after 6 encounters
(f) CMPRR-Suppl., 12/1996, p. 42; In 10,000 years



Potential extent of WIPP-12 brine reservoir using WIPP-12 pressure recovery data, rock compressibility of $1 \times 10^{-10} Pa^{-1}$, and reservoir thickness of 24 meters.

ENGINEERED BARRIERS FOR WIPP

The EPA regulations require engineered barriers to be included in the repository design as an Assurance Requirement (40 CFR 191.14d and 40 CFR 194.44). The philosophy of the Assurance Requirements is clearly stated in the "Overall Approach of the Final Rule" (Federal Register v. 50, no. 182, 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.

With respect to the engineered barriers as an assurance requirement, the "Overall Approach of the Final Rule" 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 (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 either of these to be engineered barriers, for the following reasons:

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).

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 (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?

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).

Borehole Plugs

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 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, Figure 3-9 ("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).

Recommendation

The EEG has recommended a multi-barrier approach for WIPP since the beginning of the project. The EPA regulations also require such an approach as "assurance requirements". According to the WIPP Safety Analysis Report (App. A), 88% of the WIPP bound waste is planned to be processed. At the least, the DOE should take credit for such reprocessing in the WIPP performance assessment and the CCA. EPA should encourage DOE to process the waste to make it insoluble.

<u>Enclosure</u>:
Information from the draft 1996 WIPP SAR

Information from the draft 1996 WIPP SAR
Appendix A, page A-4 to A-15
Data is from final row of cumulative values for each waste form

Stored Drum Equivalents

Final Waste Form	**Not Processed**	**To Be Processed**	
Combustible	4194	23570	
Filter	976	72	
Graphite	616	1845	
Heterogeneous	6355	104300	
Inorganic Non-metal	1168	12911	
Lead/Cadmium Metal	83	31	
Salt Waste	34	68	
Soils	95	1862	
Solidified Inorganics	15651	30670	
Solidified Organics	1077	3311	
Uncategorized Metals	3348	48751	
Unknown	129	188	
Various	0	20105	
Subtotal of column	**33726**	**247684**	Total stored **281410**
Percent of Total Stored	**11.98%**	**88.02%**	

Notes from the 1996 draft SAR
Final SAR Expected late Jan. 1997
W.T. Bartlett 1/21/97

FLUID INJECTION AND SOLUTION MINING

The EPA Requirement and the CCA

The EPA criteria (40 CFR 194.32 c) requires an analysis of the effects of fluid injection activities on the disposal system, prior to disposal and soon after disposal. The CCA has screened out the fluid injection scenario within the site on a "regulatory basis" and adjacent to the site on the basis of "no consequence" and has provided a number of arguments why it should not be considered in the performance assessment for WIPP. This paper is a critique of the CCA arguments contained in Chapter 6 and Appendix SCR. The EEG has reviewed the Stoelzel and O'Brien[1] assumptions (discussed in the CCA and later in this paper), and finds the critique by John Bredehoeft[2] (enclosed) to provide additional compelling arguments for not accepting that analysis to be valid. A copy of a consequence analysis by John Bredehoeft[3] is also enclosed. This preliminary analysis clearly establishes the importance of considering the fluid injection scenario in predicting the near-term and long-term integrity of the WIPP repository.

How Long in the Future?

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[4] 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 larger number of such injection wells, within the site, was predicted to increase with time (Ref.4, Table IV-16).

With respect to natural resource recovery activities surrounding the WIPP, the surrounding public lands are managed by either the Federal Government or the State of New Mexico. In addition to federal law, state and federal agencies know that this is a resource rich area and have developed additional policies for the effective recovery of these resources consistent with federal and state law. The Federal Land Management and Policy Act[5] states that public lands and resources are utilized to "meet the present and future needs of the American people" and take into account the "long term needs of future generations." This federal law does not limit consideration of natural resources on public lands to "near future" nor to "existing leases." On the contrary, federal agencies such as the Bureau of Land Management have explicitly argued that lessees can plan and submit plans for resource recovery activities outside their actual leases[6].

Review of Appendix SCR Arguments

The discussion of fluid injection in Appendix SCR of the CCA is incomplete and largely incorrect. For example, Appendix SCR mentions gas reinjection 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 (see the discussion in Ref.7, section 3.1.6). Further, 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.

The claim that there will be no waterflooding on the scale of Rhodes-Yates is also undermined by field evidence. The proposed waterflood at the Avalon Unit will recover 8.2 million barrels of oil by injecting 141 million barrels of water for forty years through nineteen injection wells into the Cherry Canyon and Brushy Canyon members of the Delaware Mountain Group. At Rhodes-Yates, approximately 41 million barrels of water were injected through eighteen injectors over a 26 year period. Further, the pressure maintenance wells at the Cabin Lake Unit, at the northwest corner of the WIPP Site are injecting 1.4 million barrels of water per year compared to 200,000 bbls water that were injected per year through the two pilot pressure maintenance wells at Rhodes-Yates.[7]

The CCA Appendix SCR argues that waterflooding on the same scale as the Vacuum or the Rhodes-Yates Field is unlikely because oil pools in the vicinity of the WIPP are characterized by channel sands with thin pay zones, low permeabilities, high irreducible water saturations, and high residual oil saturations. However thin pay zones tend to maximize vertical sweep efficiency and have a history of successful waterflooding throughout the United States, including the Delaware Basin. "Low" reservoir permeabilities of oil reservoirs near the WIPP area has not detered waterflooding in the mature oilfields of the Delaware Basin. Further, mature oil fields in the Delaware Basin have responded favorably to carbon dioxide flooding. The observation of high irreducible water saturations is irrelevant. A waterflood is not designed to reduce the water saturation. A waterflood designed to reduce the oil saturation and increase water saturation in the reservoir by producing the oil. The CCA comment on high residual oil saturations does not speak to the economics of waterflooding. While the Delaware sands, including those around the WIPP, produce large volumes of water, they are, nonetheless, technically and economically amenable to waterflooding[7,8] as well as CO_2 flooding[7,9,10,11,12].

The CCA-SCR cites New Mexico state regulations as also protecting the WIPP. However, the emplacement of a salt isolation string is not intended to address the needs of a 10,000 year nuclear waste repository. It is required to meet the near term safety concerns of the potash industry[13]. Further, even oil and gas wells equipped with a salt isolation string are restricted from drilling through potash reserves or near potash mining operations. With respect to brine injection wells, the potash companies and oil companies have documented their concerns[14,15,16].

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 7000 feet. One consequence of greater vertical distance is that the surface injection pressure is automatically approved for 1400 psi or 0.2 psi per foot. This corresponds to 2400 psi at the WIPP horizon which is well in excess of the fracture pressure of the anhydrite beds in the Salado Formation.

As to state regulations in general, state regulations for fluid injection have been in place for decades. Documented problems with fluid injection projects throughout southeast New Mexico identifies the limitations of state regulations. In the case of waterflood brine migrating through the Salado and damaging another oil company property, there is litigation and monetary compensation[17,18]. In the case of a nuclear waste repository, there are performance assessment calculations. However, the CCA does not include this scenario in the performance assessment calculations.

Stoelzel and O'Brien Model

The fluid injection scenario on adjacent properties for the near future has been screened out by the DOE citing low consequence as determined from calculations by Stoelzel & O'Brien[1]. It should be noted that a two dimensional, vertical model was used. Further, the assumptions used in the calculations (DOE SCR) either underestimate or fail to consider hydraulically fractured Salado anhydrite permeability, permitted surface injection pressures in the vicinity of WIPP, injection pressure gradients, the volume of disposal brine that is typically injected by oilfield operations, and the anticipated time of fluid injection activities.

The model assumes a total of 7×10^5 cubic meters of brine was injected during a fifty year period. This is equivalent to 4.4 million barrels of brine. The David Ross AIT Federal #1 salt water disposal well, which is less than a mile from WIPP, alone has injected more than 5 million barrels brine in five years of operation. And there is no basis for assuming that industrial fluid injection will not continue for the full 10,000 years.

Stoelzel and O'Brien consider only salt water disposal and assume an injection depth of 4260 feet, a surface injection pressure of 850 psi, and a pressure at the WIPP horizon of 1900 psi. However, pilot waterflooding operations near WIPP are underway for reservoirs at 7000 feet depth and have been approved to inject at a surface pressure of 1400 psi, which in the event of communication, would exert a pressure of 2400 psi at the WIPP horizon. Hence, the anhydrite beds in the Salado Formation would fracture, as successfully argued by Hartman[17] and brine would migrate for miles in the inadvertent waterflooding hydrofracture scenario.

Solution Mining

In 1979 the EEG recommended[19] that the DOE consider solution mining for salt as an intrusion scenario. 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 oilfield drilling operations. Furthermore, state records show that 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.

As to future mining of potash, solution mining is the only method that can be reasonably predicted for the Carlsbad District[20]. In Canada and the United States, solution mining is used for recovery of sylvite. Langbeinite is not readily soluble. So if solution mining is employed in the vicinity of the WIPP Site, it will be to recover only sylvite. 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. The concept would rely on the fact that the open spaces left over from mining would allow ore remaining in pillars to be recovered[20].

How can the CCA reject the solution mining scenario, if private companies surrounding the WIPP site are holding the option of using solution mining?

EEG Recommendations

Based on a technical analysis of available information, the EEG recommends that the CCA include the effect of fluid injection and all other resource recovery activities for future and existing wells drilled within the site and adjacent to the site. These activities should include:

- Waterflooding for enhanced oil recovery.
- Carbon dioxide flooding for enhanced oil recovery.
- Salt water disposal from oil production and other industrial activities.
- Solution mining for halite and sylvite.

References

1. Stoelzel, D.M. and O'Brien, D.G., 1996. The effects of Salt Water Disposal and Waterflooding on WIPP. Summary Memo of Record for NS-7a. Sandia National Laboratories, Albuquerque, N.M. WPO 40837.
2. Bredehoeft, J., 1997. January 14 Memo on Hartman Scenario—Stoelzel-Obrien Analysis to L. Lovejoy, Jr., Assistant Attorney General of New Mexico.
3. Bredehoeft, J., 1997. January 10 Memo on Hartman Scenario to to L. Lovejoy, Jr., Assistant Attorney General of New Mexico.
4. Hora, S.C., von Winderfeldt, D., and Trauth, K.M., 1991. Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant. Albuquerque, NM: Sandia National Laboratories, SAND92-0700, Appendix A.

5. Federal Land Policy and Management Act of 1976. U.S. Code Annotated, 1989. vol. 43, secs. 1701-1784
6. Vaughn, G.L., 1995. December 13 Agency Answer to Appellant's Statement of Reasons by U.S. Department of Interior Bureau of Land Management General Counsel. Yates et al., appellants. IBLA 92-612.
7. Silva, M.K., 1996. Fluid Injection for Salt Water Disposal and Enhanced Oil Recovery as a Potential Problem for the WIPP: Proceedings of a June 1995 Workshop and Analysis. EEG-62. Environmental Evaluation Group.
8. Broadhead, R.F., Luo, F. and Speer, S.W., 1995. Volume 3 of *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site*, Carlsbad, NM:
9. Jones, R.W., 1968. Hard-to-flood sand gives up secondary oil in West Texas. World Oil, September 1968, pp 72-76.
10. Wash, R., 1982. Twofreds saved by CO_2 flood. *Drill Bit*, July, 52-55.
11. Kirkpatrick, R.K., et al., 1985. Performance of the Twofreds CO_2 Injection Project. Proceedings of the 60th Society of Petroleum Engineers Annual Technical Conference, Las Vegas, Nevada, September 22, 1985, pp. 89-101.
12. Flanders, W.A. and DePauw, R.M., 1993. Update Case History: Performance of the Twofreds Tertiary CO_2 Project. SPE 26614. *Proceedings*. SPE Annual Technical Conference/Reservoir Engineering, Houston, Texas, October 3-6, 1993. pp. 41-50.
13. LeMay, W.J., Humphries, W.R., and Brustuen, E.A., 1988. Application of the Oil Conservation Division upon its own motion to revise Order-111, as amended, pertaining to the potash areas of Eddy and Lea Counties, New Mexico. Case No. 9316, Order No. R-111-P.
14. Stephenson, M.N., May 10 letter from Mitchell Energy Production-Regulatory Affairs Manager to R. Patterson, Land Manager for Yates Petroleum Corporation.
15. Heinen, R.H., 1994. January 13 letter from Western Ag-Mineral Company General Manager to J. Hansen of Bass Enterprise Production Company.
16. LeMay, W. J., 1995. December 14 Order R-10525 (Case 11403) of the Division from the Director of the New Mexico Oil Conservation District approving a pressure maintenance project for Neff Federal Well No. 23, Section 25, T22S, R31E.
17. Hartman, D., 1993. November 22 letter to Sandia National Laboratories transmitting a copy of a Complaint of Trespass, Nuisance, and Waste filed in the Federal Court for the District of New Mexico, CIV93 1349M.
18. Herrera, S., 1995. First Judicial District, County of Santa Fe, State of New Mexico, Case No. SP 93-2387 (C), Judgment in Hartman vs. Texaco, January 20, 1995.
19. Neill, R.H., Channel, J.K., Wofsy, C., and Greenfield, M.A. 1979. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy. EEG-3. Environmental Evaluation Group.
20. Griswold, G.B., 1995. Future Mining Technology. Chapter IV. Volume 2 of Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Westinghouse Electric Corporation. Waste Isolation Division. Contract No. PO-75-WJJ644145Z.

Enclosure:

Bredehoeft Memoranda dated January 10, 1997 and January 14, 1997

The HYDRODYNAMICS Group
studies in mass and energy transport in the earth

JOHN BREDEHOEFT *PhD, NAE*
principal

January 10, 1997

MEMORANDUM

To: **Lindsay Lovejoy, Jr.**

From: **John Bredehoeft**

Subject: **Hartman Scenario**

Hartman Scenario—Introduction

The so-called Hartman Scenario is based upon a law suit in the Delaware Basin. In 1991, Hartman, an independent oil operator, attempted to drill a well on the Bates lease approximately 2 miles from the Rhodes Yates water-flood project operated by Texaco The Hartman #2 Bates well encountered brine at a depth of 2240 feet; the drilling had to be terminated at 2280 feet. In 1953, the Bates #1 well was drilled without encountering pressurized brine.

Water flooding was started in the Rhodes oil field in 1959. Texaco initiated a pilot water flood in 1964. The water flood was extended in the Rhodes field in 1974. There are several active water flood projects in the Rhodes Yates area.

I reanalyzed the Hartman Scenario. In doing so, I first estimated the transmissivity of the Bates # 2 well that flowed extensively. From the transmissivity, I estimated the permeability. This should be obvious, but we are not totally sure what constituted the permeable zone in the Bates # 2 well I then: 1) compared this estimate of permeability with those measured at WIPP, and 2) estimated the inflow to WIPP should the permeabilities at the Bates # 2 site apply in the vicinity of WIPP

Transmissivity & Permeability

The Bates # 2 well flowed 840 gpm, or 1.9 cubic feet per second (cfs) The shut-in pressure at the land surface was 1000 psi—approximately 2000 feet of head at the land surface (Van Kirk, 1994). Knowing both the flow rate and the well-head, shut-in pressure there are several methods that can be used to estimate permeability. I first used the Theim, steady-state solution for radial flow to a well and solved for transmissivity, T. I then compared this result to results from two other estimating procedures.

The difficulty with the Theim approach is that we do not know how far out the cone of depression for the Bates # 2 well extended. (We can define the other boundary of the cone as the point where the drawdown caused by flow to the well is negligible.) I assumed several different radial distances for the extent of the cone (r_2), and make the calculations. The differing radial distances bracket the cone. As we see, the estimates do not vary a great deal—by a factor of only two which is small in estimating transmissivity.

$$T = 2.3\, Q \log (r_2/r_1) / [\, 2\, \pi\, (s_2 - s_1)]$$

where T = transmissivity

Q = well production rate

PO Box 352 (234 Scenic Dr) La Honda, CA 94020 (415) 747-0441/747-0273 fax jdbrede@aol.com
web site: www.mediacity.com/~hydrogup

r_2 and r_1 are selected radial distances from the center line of the well bore. I chose r_1 at the wall of the borehole approximately 0.5 ft (1 foot diameter well bore—slightly larger than the drill bit). I let r_2 be the radial extent of the cone of depression—the distance at which the drawdown is negligible.

$(s_2 - s_1)$ is the total drawdown within the cone of depression caused by the well—1000 psi. (Perhaps I need to amplify this explanation. When the well is flowing the pressure at the well head is atmospheric—which is generally defined as 0. The well head, shut-in pressure gives a us an indication of what the formation pressure would be without the well flowing. The total pressure drop when the well is flowing is 1000 psi. It could be smaller due to friction losses in the well bore—a smaller pressure drop gives a higher estimate of permeability. The total pressure drop across the cone of depression is also 1000 psi.)

I assume the brine produced a pressure of 0.5 psi per foot of brine. (Van Kirk, 1994, reports the normal pressure gradient for saturated salt water as 0.525 psi per foot; I simplified the calculation by rounding to 0.5 psi / ft.)

With r_2 = 1,000 ft.

$T = 2.3 \times 1.9 \times \log(1{,}000.0 / 0.5) / (2\pi \times 2000.0) =$ 0.0011 ft^2/sec

With r_2 = 10,000 ft

$T = 2.3 \times 1.9 \times \log(10{,}000.0 / 0.5) / (2\pi \times 2000.0) =$ 0.0015 ft^2/sec

With r_2 = 100,000 ft

$T = 2.3 \times 1.9 \times \log(100{,}000.0 / 0.5) / (2\pi \times 2000.0) =$ 0.0018 ft^2/sec

With r_2 = 1,000,000 ft

$T = 2.3 \times 1.9 \times \log(1{,}000{,}000.0 / 0.5) / (2\pi \times 2000.0) =$ 0.0022 ft^2/sec

We can also estimate the transmissivity using estimating procedures suggested by Theis et al. (1963) for pumped wells, and by Bredehoeft et al. (1983) for flowing wells. The specific capacity is 0.4 gpm per foot of drawdown, or 0.00089 ft^2 / sec per foot of drawdown. The Theis estimate yields:

T = specific capacity x 2000 (in units of gallons per day per foot)

T = 0.4 x 2000 = 800 gallons per day per foot = 0.0012 ft^2/sec.

Bredehoeft et al (1983) produced a graphical type curve; use of the Bredehoeft et al. method yields:

T = 0.0015 ft^2/sec

The estimates compare favorably; the values vary by only a factor of two. Since transmissivity can vary over 15 orders of magnitude, a factor of two variation (100%) in the estimates is considered quite good.

The permeability is less clear, only because we do not know through what vertical thickness of rock brine flowed. The drilling encountered brine at a depth of 2240 feet, and was stopped by too much flow at 2280. Assuming the entire 40 feet was permeable, the

	k = T/ thickness = 0.001 / 40.0 =	0.000025 ft/sec
or	k =	0.00075 cm/sec
	k =	0.75×10^{-12} m^2

Implications of the Analysis—Comparison to WIPP

It should be remembered that these numbers are estimated by applying a model for radial flow to/from a well. The estimate is some kind of an average permeability that applies to the entire cone of depression for the well. In other words, it is an estimate of the regional permeability within the assumed cone of depression.

The permeability of the Anhydrite marker beds was measured in-situ at WIPP. The range in anhydrite marker bed permeability data used in PA is

k anhydrite— undisturbed	7.94×10^{-18} m^2 to 10^{-21} m^2
k anhydrite—hydro-fracture maximum value (PA)	10^{-9} m^2
Hartman—Bates # 2	7.5×10^{-13} m^2

The permeability encountered in the Bates # 2 well almost surely represents hydro-fractured anhydrite in the Salado Formation. The shut-in pressure of the Bates well was 1000 psi at land surface. There were reports of oil field brine injection activities in the area with 1000 psi land surface pressures and higher (Van Kirk, 1994). Dennis Powers reported: *"For the Rhodes Yates water flood, the injection pressure at the surface ran 1200 psi and above. Some injection pressures approached 2,000 psi at the surface." (Silva, 1996, p. 67)* A pressure of 1000 psi at land surface is approximately lithostatic at a depth of 2000 feet.

The consensus interpretation of what happened in the Rhodes Yates area is that water injection at high pressure caused massive hydraulic fracturing within the Salado Formation. Numerous wells have encountered flows of water in the Salado (Van Kirk, 1994). The hydraulic fracturing has increased the Salado permeability on a regional scale. Hartman won his law suit on the basis of this hypothesis. This interpretation is consistent with our analysis of the permeability encountered in the Bates # 2 well.

Potential Flow to WIPP

It is of interest to calculate the flow to WIPP through the anhydrite marker beds. I will do two calculations with 1) unfractured anhydrite, and 2) hydro-fractured anhydrite. I will use a simplified model for analysis. I make a number of assumptions

1. two-dimensional, areal flow (x, y) in combined marker beds 139, A and B.
2. good connection between the marker beds and WIPP,
3. single-phase, liquid flow only;
4. steady flow (not transient),

5 that fluid is injected with a pressure at a land surface of 1000 psi (68 atmospheres)—pressures like that measured at the surface in the Bates # 2 well; (This is lower than the 1200-2000 psi pressures reported for surface pressures of injection wells in the Texaco Rhodes Yates water flood. As we will see, 1000 psi poses problems.)

6 that the casing of the injection well fails, and 1000 psi surface pressure is imposed on marker beds 139, A and B:

7 in the hydro-fractured case that the marker beds have a regional permeability equal to that at the Bates # 2 site—7.5×10^{-13} m^2 ; (This assumption deserves more explanation. I suggested above that the hydraulic fracturing in the vicinity of the Texaco Rhodes Yates water flood increseased the permeability on a regional scale. I am assuming that similar, regional scale hydraulic fracturing occurs in the vicinity of WIPP.)

8 the repository is at hydrostatic pressure and remains at hydrostatic pressure; (Early in the history of the repository the pressure could be more nearly atmospheric. As the repository receives significant flow the pressure will increase. For this analysis, I neglect both the early pressure history below hydrostatic, and the later potential pressure build-up above hydrostatic If one examines the pressure histories of WIPP computed by PA, hydrostatic pressure is the dominate mode.)

9. since the region of the model is finite, I assume no flow boundaries at the edge of the modeled region. (These boundaries force the flow to go to WIPP where the head is held hydrostatic. Ideally, we would like no head build-up at the boundaries; as one can see below there is some build-up at the model boundaries. This condition can be relaxed by extending the model outward In the hydro-fractured case the permeability is increased in a restricted area; therefore the outer, no-flow boundary may not be as bad an assumption as might appear at first glance. The region model is fairly large; and the boundaries are somewhat removed from the area of principal interest.)

The results are summarized in the following table:

Table 1 Flow to WIPP

	Distance from well to WIPP	Well-head pressure (psi)	Permeability m^2	Flow rate m^3 / sec	Flow rate m^3 / day
Model 1	2 km	1000	10^{-18}	7×10^{-9}	0.0006
Model 2	2 km	1000	7.5×10^{-13}	5×10^{-3}	430.0 (157,000 / yr)

Note- -the approximate total pore volume of the repository, after the salt deforms, is 30,000 m^3.

It is of interest to examine the head distribution produced by this models. The head is the same for each permeability distribution; even though, as Table 1 shows, the flows are quite different The attached Figure is an isometric projection of the head. One can picture the flow if you remember that flow is directly down the gradient in head—it is analogous to a marble rolling down hill.

Concluding Remarks

Injection fluid pressures in the vicinity of the Bates lease were high. It seems clear from the data that the pressures were sufficiently high to produce massive hydraulic fracturing over a large area that included the Bates # 2 well. The permeability, as estimated from the well, is five orders of magnitude higher than the highest undisturbed measurements at WIPP. On the other hand, the Bates # 2 well permeability is three orders of magnitude lower than the maximum hydro-fracture permeability used in Performance Assessment.

Fluid injection in the vicinity of WIPP has the potential to quickly fill the repository with brine should the operation be similar to that which occurred in the vicinity of the Bates lease. The Hartman Scenario is not easily dismissed.

References

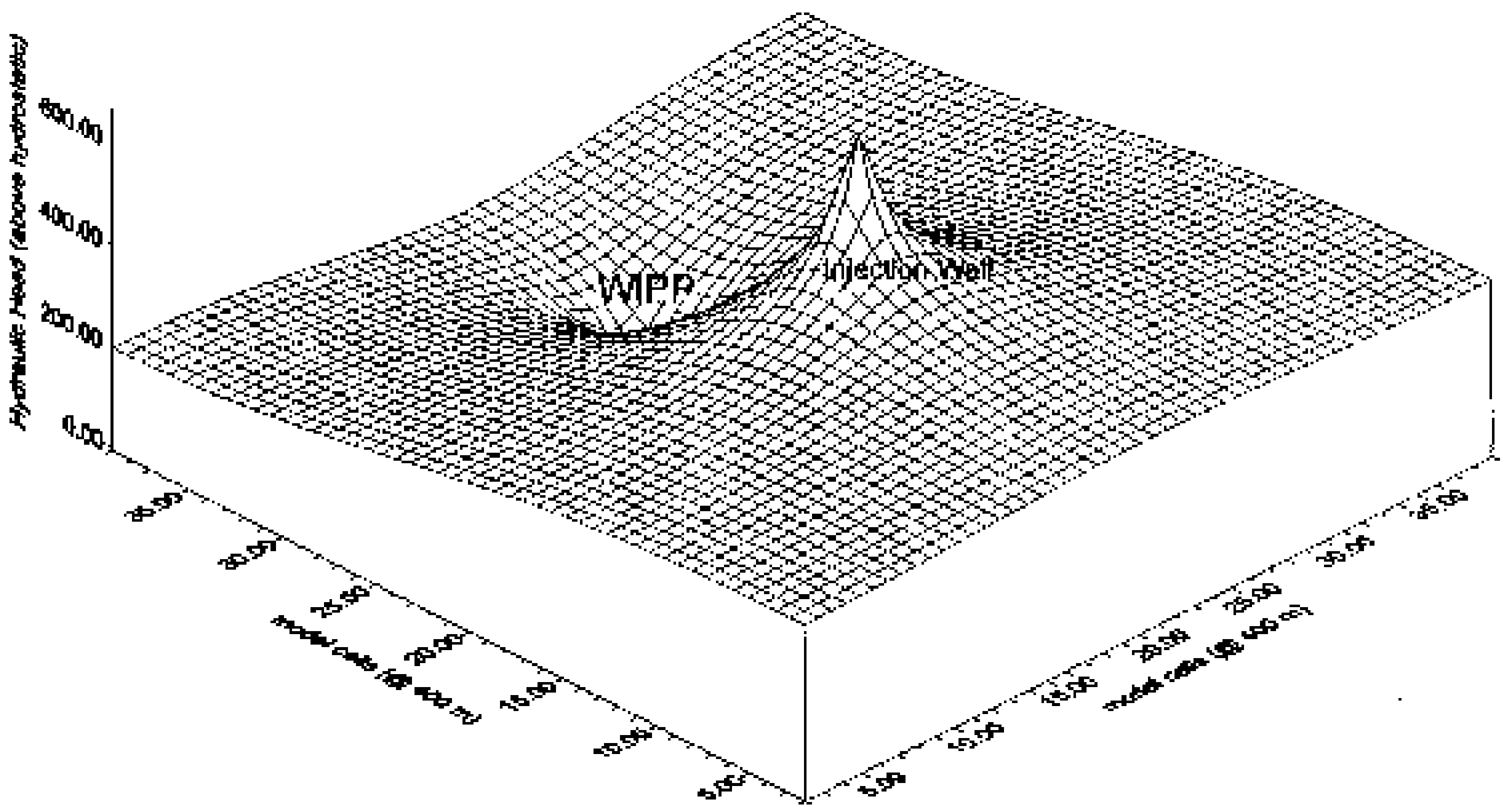
Bredehoeft, J.D., C.E. Neuzil and P.C.D. Milley, 1983, *Regional flow in the Dakota Aquifer: a study in the role of confining layers:* U.S. Geological Survey Water Supply Paper 2237, 45 p.

Silva, M.K., 1996, *Fluid injection for salt water disposal and enhanced oil recovery as a potential problem for the WIPP: proceedings of a June 1995 workshop and analysis:* Publication of New Mexico Environmental Evaluation Group # EEG-62, 188 p.

Theis, C.V., R.H. Brown and R.R. Meyer, 1963, *Estimating the transmissibility of aquifers from the specific capacity of wells:* U.S. Geological Survey Water Supply Paper 1536-I, p I1331-I1341.

Van Kirk, C., 1994, *Report concerning salt water blow-out January, 1991 on the Bates lease—sections 10 and 15, township 26 south, range 37 east, NMPM, Lea County, New Mexico: 16 p, plus figures and appendices.*

WIPP--Hartman Scenario
(head above hydrostatic)



The HYDRODYNAMICS Group
studies in mass and energy transport in the earth

JOHN BREDEHOEFT *PhD, NAE*
principal

January 14, 1997

MEMORANDUM

To: **Lindsay Lovejoy, Jr.**

From: **John Bredehoeft**

Subject: **Hartman Scenario—Stoelzel-O'Brien Analysis**

Introduction

Stoezel-O'Brien did a cross-sectional analysis. I modeled a cross-sectional to compare with our areal analysis and show you the difference.

Analysis

I selected a cross-section strip that is two model cells in width—a total width of 800 meters. This is approximately as wide as the smaller dimension of the repository foot print. As before, I placed the injection well 2 km from the repository. I used the permeability estimates from the Hartman # 2 Bates well. I assumed an injection pressure of 1000 psi at land surface; held the repository at hydrostatic head; and did a steady-flow calculation.

This analysis is analogous to our previous analysis except that we now have flow only in the cross-sectional strip. Enclosed is an isometric plot of head for comparison.

Results

The results are summarized in the following table:

Table 1 Flow to WIPP

	Distance from well to WIPP	Well-head pressure (psi)	Permeability m^2	Flow rate m^3 / sec	Flow rate m^3 / day
Model 1 (areal)	2 km	1000	10^{-18}	7×10^{-9}	0.0006
Model 2 (areal)	2 km	1000	7.5×10^{-13}	5×10^{-3}	430.0 (157,000 m^3/yr)
Model 3 (strip)	2 km	1000	7.5×10^{-13}	1×10^{-3}	86.4 (31,600 m^3/yr)

Note—the approximate total pore volume of the repository, after the salt deforms, is 50,000 m^3.

As you can see, restricting the flow to a cross-sectional strip reduces it to approximately 1/5 of the amount in areal model. This is the conceptual difficulty with the Stoezel-O'Brien approach.

PO Box 352 (234 Scenic Dr) La Honda, CA 94020 (415) 747-0441/747-0273 fax jdbrede@aol.com
web site: www.mediacity.com/~hydrogup

The HYDRODYNAMICS Group

studies in mass and energy transport in the earth

WIPP Analysis

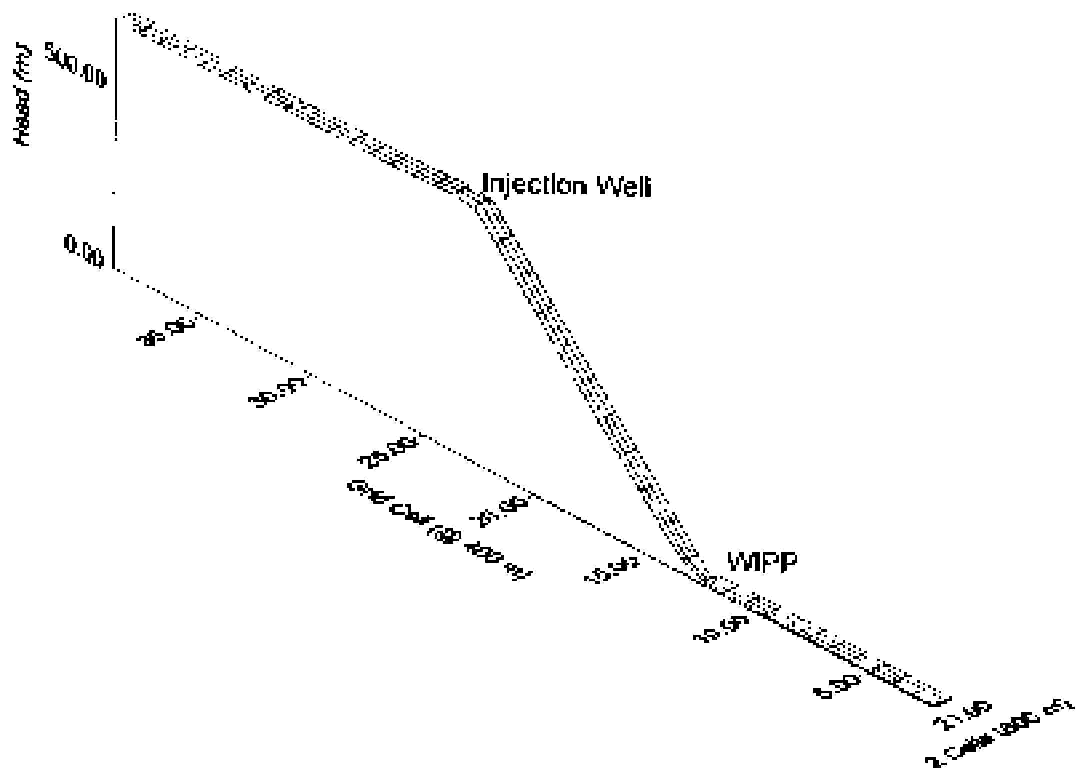
Flow to/from WIPP is three dimensional. Sandia claims, perhaps correctly, that analyzing the full 3D flow problem is much too computer intensive to be practical for PA. For this reason the problem is idealized currently into a plane—a cross-section in the case of WIPP. (Two dimensional analyses, either areal—x, y; or cross-sectional—x ,z; or radial—r, z, are the rule in analyzing flow problems.) Any of 2D geometry is an approximations for the 3D problem. The simplification is a compromise—sometimes good, and sometimes not so good. You can see that the Stoezel-O'Brien cross-section was not very good for analyzing flow to WIPP.

In previous PA analyses a radial formulation was used in which radial distances were measured out ward from the disposal room. This formulation did not handle the connection between the disposal panel and the rest of the repository very well. This was changed to a cross-section in an effort to improve this portion of the modeling. The new cross-section will not do well in handling flow outward in the marker beds, the radial model was better in this instance.

I know that Chuck Byrum is concerned about the 2D approximations used in WIPP PA. EPA has had HydroGeologic looking into these approximations.

My gut reaction is that most of the approximations associated with the cross-sectional analysis used in BRAGFLOW are probably okay—assuming a 2D analysis is the only one practical. As I suggested to Sandia when it was presented, the Stoezel-O'Brien cross-section concept used for analysis was poor, at best.

PO Box 352 (234 Scenic Dr) La Honda, CA 94020 (415) 747-0441/747-0273 fax jdbrede@aol.com
web site: www.medlacity.com/~hydrogup


Head (m)
500.00
0.00
Injection Well
WIPP
25.00

ENVIRONMENTAL EVALUATION GROUP
AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003
FAX (505) 828-1062

March 14, 1997
Director,

Center for the Waste Isolation Pilot Plant Program
U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
401 M. Street S.W.
Washington, D.C. 20460

Dear Mr. Marcinowski:

Enclosed please find the EEG's additional comments on significant issues arising from our review of the WIPP Compliance Certification Application (CCA). This package of 14 papers complements the package of 6 papers submitted to you on February 7, 1997, following the same format.

Please note that as we continue to explore deeper into the assumptions, professional judgements, calculations, conceptual and numerical models, and secondary documentations related to the CCA, we are bound to come up with additional issues to be sesolved. We do not view the March 17, 1997 deadline as a bounding date for communicating additional concerns to the EPA. Given the significance of the decision that the EPA has to make, and the time that the DOE has taken to prepare this application since EPA originally promulgated 40 CFR 191 in 1985, 4 months of review time is not enough. Actually, the review time was much shorter since many of the issues that we have identified required a review of the Sensitivity Analysis Report that was provided to the EEG on January 20, 1997, and additional materials that have only recently been added to the Records Packages at the Sandia National Laboratories.

A detailed review of the July 1995 DOE draft CCA (DCCA) was provided by the EEG to the DOE in February 1996 and later published as the EEG report, "Review of the WIPP Draft Application to Show Compliance with EPA Transuranic Waste Disposal Standards", EEG-61, March 1996. The EEG has not received comments on that review from the DOE to date, and we have found no changes between the draft and the final CCA as a result of the EEG review (EEG-61). In our additional comments on the CCA to be provided in a report that we plan to publish this year, we will analyze our comments on the DCCA and how they have been treated in the CCA. At this time, we are formally submitting a copy of EEG-61 to you and to the Docket as part of our comments on the CCA.

The issues identified in EEG-61, our letter and encloserues date 2/7/97, and this letter and the enclosures, should therefore be considered to be our formal comments on the CCA submitted to you before 3/1797 deadline. As you can see, we have concentrated our efforts so far on reviewing the Containment Requirement related issues of the CCA. We will provide comments on the other parts of the 40 CFR 191 subpart B compliance as we review the compliance with them.

The overall EEG recommendation to the EPA at this point is to require the DOE to include consideration of additional scenarios like water-flooding and solution mining, with corrected conceptual models and parameter values in showing compliance with the Containment Requirements of the EPA Standards, 40 CFR 191. EPA should also require robust engineered barriers as part of the Assurance Requirement of 40 CFR 191.

Sincerely,

Robert H. Neill
Director

RHN:LC:pf
Enclosures: EEG Reviews of the WIPP CCA

Brine Reservior Assumptions in the CCA (Revised)
Faulty Sapling Ranges
Brine Inflow from Salado: 2D versus 3D Geometry in BRAGFLO
Probability of Microbial Degradation
Borehole Plug Lifetime
Inconsistency Between Direct Brine Release and Spallings Geometry
Waste Permeability Values
Random Emplacement of the Waste in the Repository
Residual Brine Saturation of Waste
Compendum of Direct Brine Release Problems
Active Institutional Controls
Passive Institutional Controls
Potash Mining
Documentation of FEPs and Parameters

cc: Ms. Jennifer Salisbury, NMEMNRD
Mr. Lindsay Lovejoy, Jr., NMAG
EPA Docket for WIPP (A-9302)

BRINE RESERVOIR ASSUMPTIONS IN THE CCA (Revised)

This section updates EEG's previous submission of 2/7/97 to the EPA on brine reservoir assumptions. A new section, "Revisions to Parameters" has been added to address issues raised in the January 16, 1997 memo of Rick Beauheim to Palmer Vaughn[1]. No other changes have been made to the original submission.

The EEG sees no justification for assuming only 8% probability of intercepting a pressurized brine reservoir in the Castile Formation 250 meters below the repository. The fatal flaw in the CCA argument for 8% is the assumption that the oil and gas wells that did not report encountering brine did in fact not encounter a brine reservoir. The fact is that the drillers are not required to report brine encounters to the state or federal authorities and no mention would be found in the records unless undue delays or hazardous conditions are encountered.

The 8% probability also ignores the data from WIPP-12 and the TDEM survey over the repository. The borehole WIPP-12 is located north of the repository within the WIPP site. It was drilled to the bottom of the Salado Formation in 1978 and deepened in 1981 at the EEG's suggestion. The DOE contractor (Popielak et al., WIPP-TME-3153, 1983) estimated the volume of the reservoir to be 2.7 million m^3 (17 million barrels). For the maximum possible reservoir thickness of 24 meters, the surface footprint of a cylinder containing this volume would have a diameter of more than 3 km. As the attached figure shows, the WIPP repository is most likely underlain by the brine reservoir encountered by WIPP-12. In addition, the TDEM survey (SAND 87-7144) gives an indication of the presence of brine at the upper Castile horizon. To try to assign specific areas of the presence of brine from this geophysical survey would be over-interpretation of the geophysical data. Combination of the WIPP-12 data and the results of the TDEM survey indicate the existence of brine under the repository. Any borehole drilled into Castile under the repository should therefore be assumed to encounter brine.

The EEG does not find the CCA reservoir volume assumption of 32,000 to 160,000 m^3 to be justified. This is based on the assumption of depletion of reservoirs by future drillers - 100% probability of encounter for the depletion assumption, while only 8% for releases!

The attached table shows the comparison between the characteristics of the WIPP-12 brine reservoir and the CCA assumptions.

The WIPP site was moved twice; in 1975 after the borehole ERDA-6 encountered a brine reservoir, and again in 1982, after WIPP-12 encountered brine. The CCA assumptions of probability should be realistically based on the site specific information, and the characteristics should be based on the WIPP-12 experience.

---

[1]Beauheim, R., Revisions to Castile Brine Reservoir Parameter Packages, memo to P. Vaughn, in WPO 31084, Sandia National Laboratory, January 16, 1997.

The DOE Conceptual Model Peer Review Panel, in their December 1996 report, essentially agrees with the EEG position, but has accepted the DOE position that there are no significant consequences of the probability and volume assumptions.

The EEG does not accept the "no consequence" argument that is based on piecemeal, partial sensitivity analyses.

Revisions to Parameters

On January 16, 1997, Rick Beauheim of Sandia National Laboratories recommended revising five parameters describing the Castile brine reservoir conditions[1]. The reasons for these changes are presented in the parameter record packages WPO 31070, 31072, 31082, 31083, and 31084. 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 combination of the TDEM survey and the estimates of the areal extent of the WIPP-12 brine reservoir provides a strong evidence that the WIPP-12 reservoir and the brine under the repository are one and the same. Therefore, only the WIPP-12 brine reservoir characteristics should be used to define the parameters used in the CCA performance assessment.

Beauheim points out that the parameters should be constrained by what he terms the productivity

$$PR = V \frac{C_r}{f}$$

ratio (PR), given by:
Where V is the sampled reservoir volume, C_r is the rock compressibility and ϕ is the porosity. Beauheim's recommended range for this constraint is 7×10^{-4} to 4×10^{-2} m^3/Pa, in which the 7×10^{-4} m^3/Pa value is from ERDA-6 data and 4×10^{-2} m^3/Pa is consistent with the WIPP-12 data. The constraint PR should be fixed at 4×10^{-2} m^3/Pa in order to agree with the WIPP-12 data, and the ERDA-6 data should not be used because it is irrelevant to the present WIPP site. Thus, with porosity fixed, the reservoir volume (V) should be inversely correlated with the sampled value of rock compressibility so that PR equals 4×10^{-2} m^3/Pa. Attached is a figure from an October 3, 1996 memo from Rick Beauheim to Les Shephard[2] showing PR calculated from the sampled parameters of the CCA calculations. The figure has been modified to point out the 4×10^{-2} m^3/Pa value determined for WIPP-12. Only five out of 300 samples were as large as the WIPP-12

---

[2]Swift, P.N., K.W. Larson, and R.L. Beauheim, Treatment of Castile Brine Reservoir in the 1996 CCA Performance Assessment, Memo to L.E. Shephard, WPO 41885, Sandia National Laboratory, October 3, 1996.

measurements. This figure clearly demonstrates the inappropriateness of the Castile brine parameters used in the CCA calculations.

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.

Comparison of WIPP-12 Brine Reservoir and the CCA Assumptions

Parameter	WIPP-12 (m^3)	CCA (m^3)
Total Reservoir Volume	2.7×10^6 (a)	32,000 to 160,000 (d)
Projected Max. Artesian Flow	55,821 (b)	5,200 (e)
Flow to Surface During Drilling	4,306 (c)	400 to 2,100 (f)

(a) WIPP/TME-3153, p. H-54
(b) WIPP/TME-3153, p. H-55
(c) WIPP/TME-3153, p. H-9; Actual "unavoidable" flow
(d) DOE/CAO-1996-2184, Table 6-26; Beauheim (1/16/97 Memo to Vaughn) revised the estimate to 100,000 to 1,700,000 m^3
(e) CMPRR-Suppl., 12/1996, p. 42; To the Culebra, after 6 encounters
(f) CMPRR-Suppl., 12/1996, p. 42; In 10,000 years

Reservoir Production vs. Reservoir Volume-Compressibility Product, First CCA Replicate F1 at 1000 Years

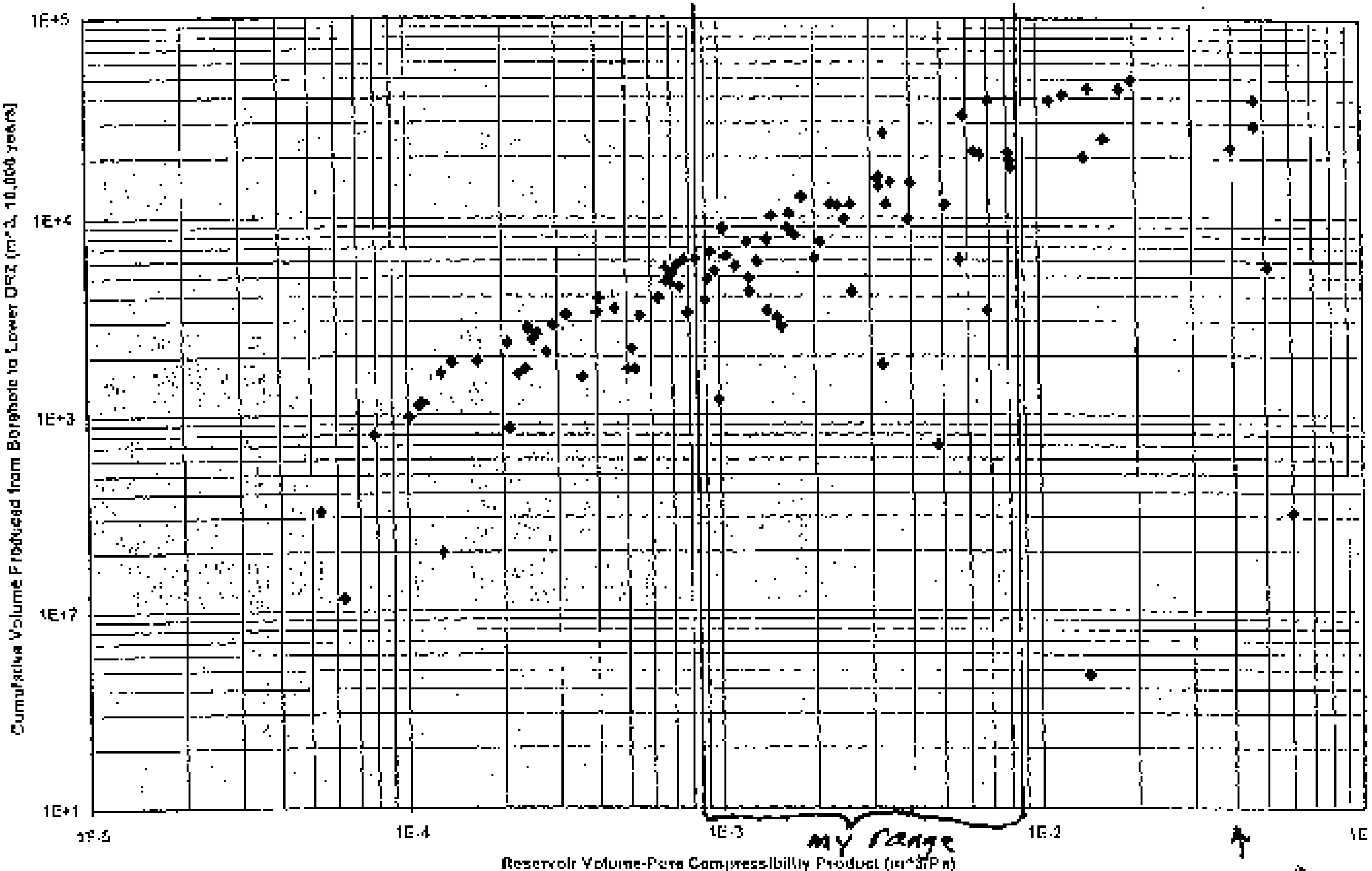
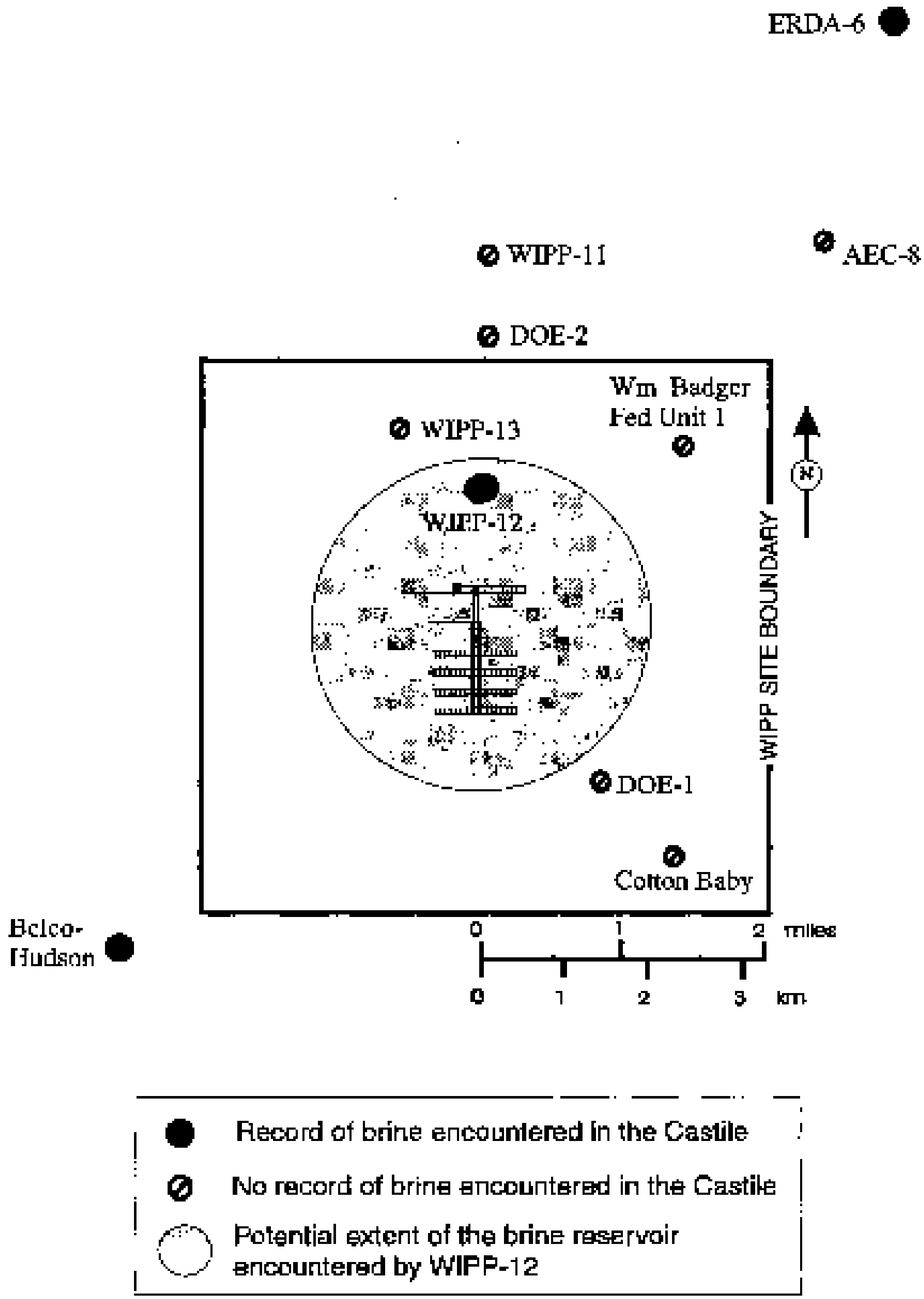


Figure 2

Figure 1 (From Swift et al., 1996)

INFORMATION ONLY



Potential extent of WIPP-12 brine reservoir using WIPP-12 pressure recovery data, rock compressibility of 1x10[illegible]Pa^{-1}, and reservoir thickness of 24 meters.

FAULTY SAMPLING RANGES

Recently, arguments have been made that if the sampled distributions of parameters used in the CCA calculations are in error, but include the likely values of those parameters, then the CCA calculations are acceptable. We disagree. 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 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.

In this report we state our case in two ways - first by example and then abstractly. The most notable occurrence of a faulty parameter distribution is the Castile brine reservoir volume distribution used in the CCA calculations. The error has been admitted by DOE and considered by the conceptual model peer review panel.

1) The Brine Reservoir Example

This example demonstrates the pitfalls of accepting parameter errors as inconsequential in a piecemeal fashion. The conceptual model peer review panel accepted the argument that the brine reservoir parameters were acceptable because the correct values were effectively included in at least some of the sampled vectors. They also concluded that the brine reservoir interception probability was inconsequentially in error because encounters with a brine reservoir, E1 events, do not have substantially different consequences from intrusions that do not encounter brine, E2 events. They reached this conclusion through inspection of results presented for the entire set of sampled vectors. First, their basic conclusion was flawed because the repository system is too complicated to be evaluated using the data presented. Second, they had no way to evaluate the effect of the biases introduced by the flawed reservoir volume parameter distribution on the data presented.

The EEG understands that the DOE currently considers the parameter distribution for the brine reservoir volume to be from 10^5 to 1.7×10^6 m^3 rather than the range of 3.2×10^4 to 1.6×10^5 m^3 as used in the CCA calculations[3]. In the first supplemental conceptual model peer review report, the panel concludes that the error in volume is of no consequence because the pore compressibility-volume product range of the calculations includes the correct range[4].

---

[3]Beauhiem, R., Revisions to Castile Brine Reservoir Package Packages,memo to P. Vaughn, in WPO#31084, Sandia National Laboratories, January 16, 1997.

[4]Wilson C., D. Porter, J. Gibbons, E. Oswald, G. Sjoblom, and F. Caporuscio, Supplementary Conceptual Models Peer Review Report, DOE, Dec. 1996, Page 41.

Later, the peer review panel used the comparison of plots of brine inflow, brine saturation, and gas generation from the both E1 and E2 intrusions to conclude that the intersection of the brine reservoir insignificantly impacted the releases and hence the probability of intersecting a reservoir was unimportant to the CCA calculations. The plots included data from all vectors of replicate 1 with no indication of which data were from vectors with the acceptable pore compressibility-volume product range.

The data the peer review panel used for their decision was inadequate. This conclusion is based on our interpretation of Figures 5.1.6 and 5.1.7 of the preliminary sensitivity analysis report on the CCA Calculations[5]. Figures 5.1.6 and 5.1.7 contradict the panels conclusion. Figure 5.1.6 presents volume and EPA unit releases for the different specified second intrusion times for an initial E1 intrusion at 350 and 1,000 years. Figure 5.1.7 presents similar release data for initial E2 intrusions. For initial intrusions of 350 years, and especially at earlier second intrusion times, Figure 5.1.6 presents substantially larger volumetric and radionuclide releases. The average volumetric release is almost two orders of magnitude higher for a second intrusion at 200 years after the E1 event compared to the E2. Because of assumed solubility differences in Castile and Salado brine, the normalized EPA release is only a factor of 30 higher 200 years after an E1 at 350 years. Since EEG has stated elsewhere that the solubility differences for plutonium are much smaller than assumed for the CCA, the comparison of volumetric releases may be a better indication of the differences. However, such a comparison is biased toward low volumetric releases in the case of an initial E1 event by the use of a flawed distribution of the pore compressibility-volume product.

With a pore-compressibility-volume product equivalent to WIPP-12, the probability of brine reservoir encounter set to 1. and, plutonium solubilities consistent with experimental data, the possibility that direct brine release will violate the compliance criteria can not be ruled out based on our present understanding of the CCA modeling.

2) General Considerations

Construction of CCDF curves to demonstrate compliance with 194 Part B requires estimates of the uncertainty in parameter values. Sampling over the parameter uncertainty ranges incorporates this uncertainty in the CCDF curves. Sampling also provides some assurance that deviations from reality, of best estimates for the repository system, will not have disastrous consequences. Thus, the parameters ranges must capture the true uncertainty in the results, unless compensating conservatism is used.

---

[5] J. Helton, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Dec. 23, 1996.

If the parameter ranges are in error then the mean value of the CCDF curves will be biased and the distribution of the curves no longer represent the uncertainty in the understanding of the WIPP site. An error in this context means an incorrect representation of current understanding and should not be confused with an inaccurate understanding. Errors in the analysis are recognizable and correctable. The concern here is the consequence of recognizing an error but failing to correct for it. The basis for such a decision could be that the error does not matter or leads to higher CCDF curves. The decision to not correct a parameter error should only be made if the effects of the parameter are completely understood and the insensitivity or conservatism in the results can be clearly demonstrated.

Demonstrating the consequences of errors in most of the CCA parameter ranges would be difficult. The difficulty is compounded by potential interactions of errors in more than one parameter. Not only the effect on the CCA calculations must be demonstrated but the effect on potential calculations under conditions that may be caused by the other parameters must also be included. The effort could easily be much greater than the effort of a completely new set of CCA calculations and yet still fail to provide an adequate demonstration of the consequences.

The most reliable way to eliminate concerns about parameter errors is to rerun the CCA calculations with the proper values. It makes little sense to do so in a piecemeal fashion. The CCA calculations should be rerun only after a complete evaluation of the current set of calculations. Otherwise it will be nearly impossible to credibly provide reasonable assurance that the compliance criteria are met.

BRINE INFLOW FROM SALADO: 2-D VERSUS 3-D GEOMETRY IN BRAGFLO

The 2-D geometry used in the BRAGFLO appears to have caused an under-prediction of brine inflow to the repository and thus may have resulted in a significant under-prediction of the direct brine release. This assumption may also have effected the amount of releases predicted by the spallings scenario.

The justification for modeling the repository in a pseudo 3-D manner (2-D radial flaring) rather than in a full 3-D geometry has been provided through evaluation of FEP S-1[1]. The summary memo of record for the FEP S-1 screening analysis discusses the impact of the 2-D assumption on 1) brine flow through the anhydrite layers to the 2.4 km boundary, 2) flow to the top of the shaft, 3) brine flow up the borehole, and 4) the repository pressure. That memo[6] does not consider the effects of the 2-D assumption on the inflow of brine to the repository, and on the spallings or direct brine releases.

The amount of projected inflow of brine in the repository directly effects the gas pressure in the repository. Table 5.5.3 of the sensitivity analysis reported[7] lists the residual gas saturation as the parameter with the strongest influence on the projected direct brine releases. This is also shown in Figure 5.1.5 of the sensitivity analysis report (the attached Figure 1). In addition, brine inflow is important to the spallings release estimates through increased gas generation. This dependence is made clear in Table 4.4.3 of the sensitivity analysis report which lists halite porosity, a large source of brine, as the second most important parameter to spallings releases.

The screening analysis compared 2-D simulations of the repository to 3-D simulations of the repository. For computational efficiency, the calculations were performed for half the repository. Two sets of simulations were conducted for the analysis. One set of calculations used a gas generation rate below the level that would cause anhydrite bed fracturing. The second used twice the gas generation rate to ensure anhydrite bed fracturing. In both sets, less brine-inflow occurred in the 2-D case compared to the 3-D geometry. No dependency of gas generation on brine inflow to the repository was included in the calculations; gas generation was prescribed as a function of time, ending after 1,000 years in the screening calculations.

---

[6] Vaughn, P., T. Hadgu, D. McArthur, and J. Schreiber, FEP Screening Analysis S1: Verification of 2D-Radial Flaring Using 3D Geometry, Memorandum to D.R. Anderson, January 26, 1996, WPO 30840, Sandia National Laboratory, Attachment 4-1 to Appendix Mass of the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, DOE/CAO-1996-2184, December, 1996.

[7] Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

The largest impact of 2-D geometry occurs with anhydrite bed fracturing. The 3-D model predicts the flow into the repository to significantly increase if the anhydrite beds fracture, while the 2-D model predicts the flow to decrease in relation to calculations without anhydrite fracturing.

Figure 15 of the FEP S-1 analysis (Figure 2) shows the cumulative brine inflow to the repository for the high gas generation calculations. The flows calculated using the 3-D model indicate that once anhydrite bed fracturing occurs, roughly $2x10^6$ kg (1,600 m^3) of brine enters the repository in a period of 200 to 300 years and that this flow rate was continuing unabated at the time of drilling intrusion. Another $4x10^6$ kg (3,200 m^3) flowed into the repository shortly after the drilling intrusion. Figure 2 shows differences of $4x10^6$ to $6x10^6$ kg (3,200 to 6,500 m^3) for much of the 10,000 years. The brine inflow differences listed above should be doubled for the full repository. Virtually no flow enters the repository as a result of anhydrite bed fracturing in the 2-D geometry. In fact, the net flow over the 10,000 year simulation is less with anhydrite fracturing compared with the simulation without the beds fracturing. Figure 2.1.4 of the sensitivity analysis report[2] (Figure 3) indicates very little marker bed inflow with microbial gas generation of plastics and rubber, supporting the findings of the FEPs analysis. Figure 5.1.5 of the sensitivity analysis report reveals the importance to direct brine release of these low brine inflows. The highest pressures are correlated with brine saturations below the residual brine saturation of the waste. The low saturations are due partly to increasing repository pore space with increasing pressure and partly to lower brine inflow.

Table 2.5.13 of the sensitivity analysis report indicates that the potential for anhydrite bed fracturing is high. As a crude approximation, consider the undisturbed scenario of a total fracture-enhanced flow of 20,000 m^3 over a period of 2,000 years. The highest repository pressure in the FEP S-1 calculations was 13 MPa. This corresponds to a repository pore space of 85,000 m^3 (Figure 2.3.5 of the sensitivity analysis report). The increased brine flow would increase the average brine saturation by 0.23. The CCA calculations do not include simulations of both very high pressure and brine saturations above the residual brine saturation of the waste. Inspection of Figure 5.1.5 suggests a significant impact from a 0.23 saturation shift at high pressures.

The simulations without anhydrite fracturing show a decrease of $1x10^6$ to $2x10^6$ kg (800 to 1,600 m^3) in predicted brine inflow in the 2-D simulations compared to the 3-D simulations (Figure 4; Figure 10 of the FEP S-1 memo). These flows are doubled for the full repository. The differences are most likely from differences in marker beds flows to the repository.

To put these brine inflow differences in perspective, note that average brine inflow to the repository in the CCA calculations of the similar S5 scenario was almost 40,000 m^3, with an average 8,000 m^3 from the marker beds[2]. Marker bed brine flows in the S5 scenario are dominated by flows under low pressure conditions. The marker bed flows are a more significant concern in the S1 undisturbed scenario. An average of roughly 3,000 m^3 flowed into the repository from the marker beds in the S1 CCA calculations. To approximate the brine flow error in the undisturbed calculations for pressures below the anhydrite fracture threshold, we ratio the FEP S-1 differences by 3,000/8,000 - resulting in the range of 600 to 1,200 m^3 less brine inflow to the full repository. If 1,200 m^3 of brine were distributed throughout the entire repository it could increase the average saturations by 0.015 to 0.03 (0.04 to 0.08 in the S5 scenario and 0.16 to 0.32 after anhydrite fracturing in an S5 scenario). It is more likely that much of the additional brine would be consumed through increased gas generation, leading to higher repository pressures.

There are indications in the sensitivity analysis report that the computational grid effects the distribution of brine within the repository in addition to the overall magnitude of brine. One indication is the statement on page 2-26 that "Due to the computational grid in use (Fig. 1.2.1), the lower panel receives more brine inflow from the marker beds relative to its size than the upper waste panels (Fig. 2.1.2)." Another indication may be the importance of the residual gas saturation of the shaft seals to flow through the marker beds (Table 2.1.1 of the sensitivity analysis report). As stated in the report, "its selection may be due to effects related to brine and gas movement across the part of the computational grid that corresponds to the shaft in the repository and DRZ (i.e., regions 10,11 in Fig. 1.2.1)." As a result, the upper waste panels receive roughly one ninth of the brine inflow from the marker beds per panel as the lower waste panel. In a large fraction of the sampled vectors, gas generation stops in the upper panels because of limited brine availability for steel corrosion. Thus, the CCA calculations are under-predicting repository pressure as well as brine saturation.

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 re-examined with appropriate consideration of the impact of increased brine saturation on calculated release estimates.

Figure 1

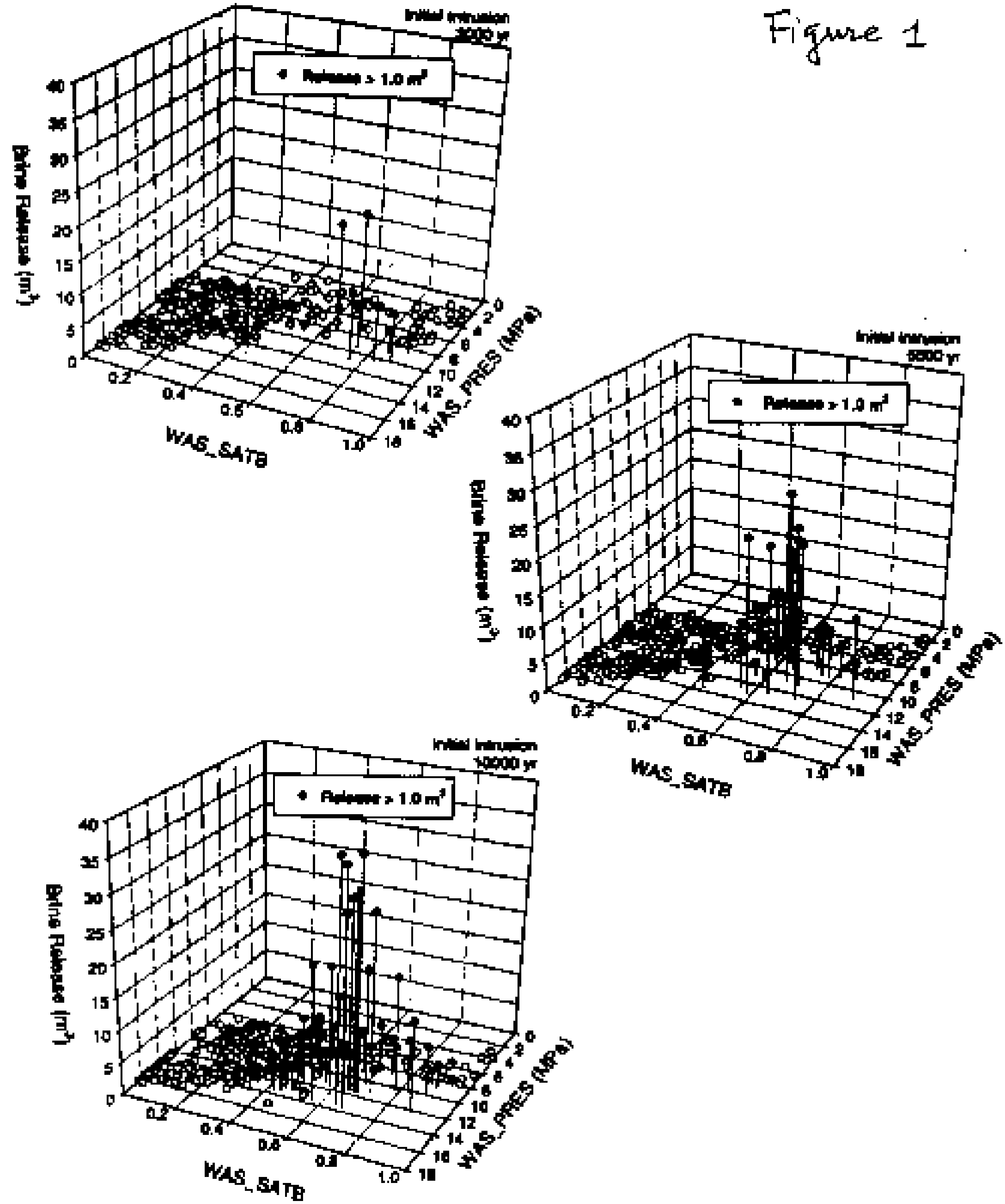


Fig. 5.1.5. Three dimensional scatterplots for volume of brine (m^3) removed due to direct brine release resulting from a single drilling intrusion into a previously unintruded repository that passes through CH-TRU waste in a lower waste panel, brine saturation and pressure (MPa).

From: Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

Figure 2

From: Vaughn, P., T. Hadgu, D. McArther, and J. Schreiber, FEP Screening Analysis S1: Verification of 2D-Radial Flaring Using 3D Geometry, Memorandum to D.R. Anderson, January 26, 1996.

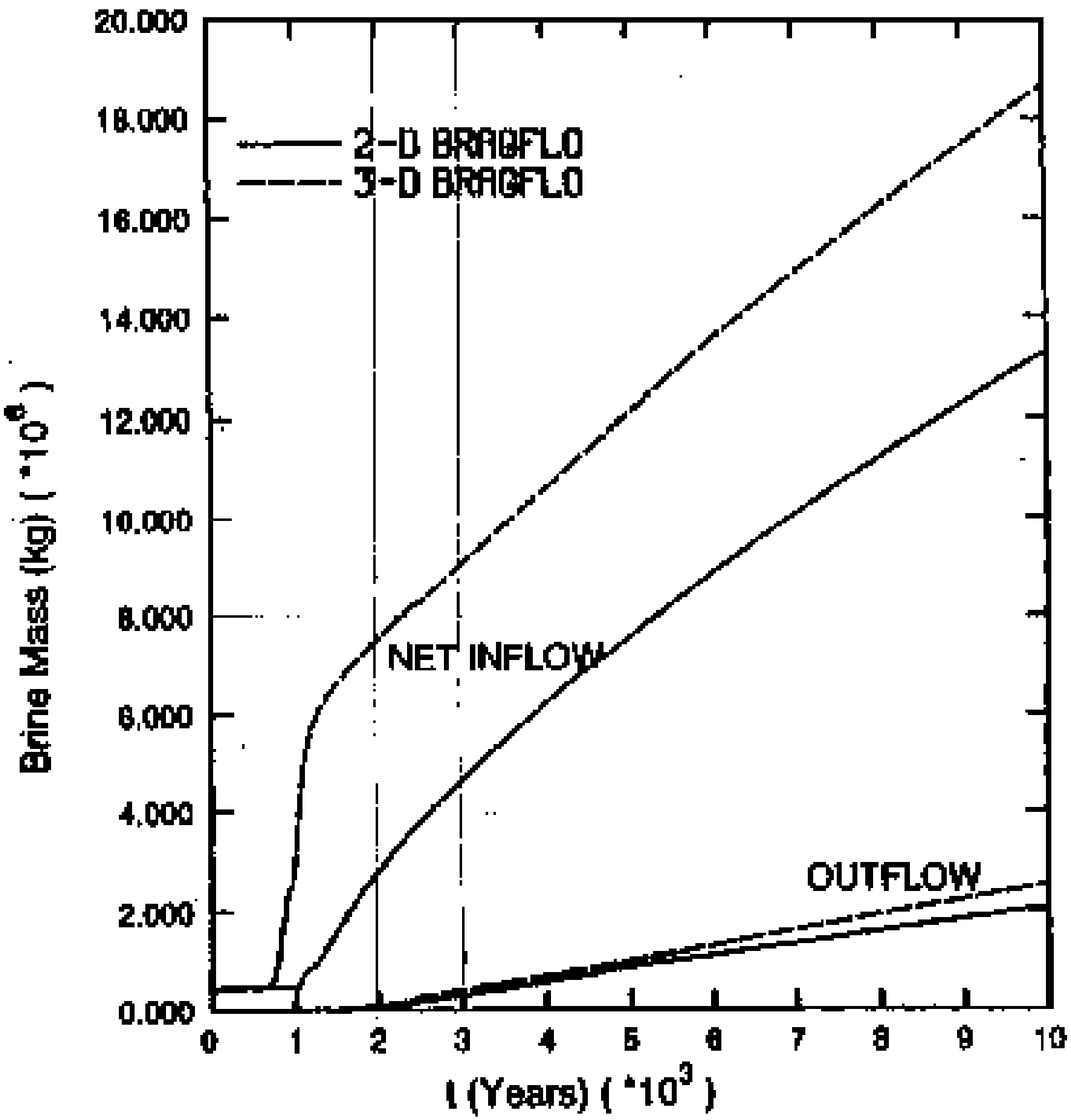


Fig. 15 Cumulative Net Brine In and Outflow at Repo.-Doubled Gas Generation rate

Figure 3

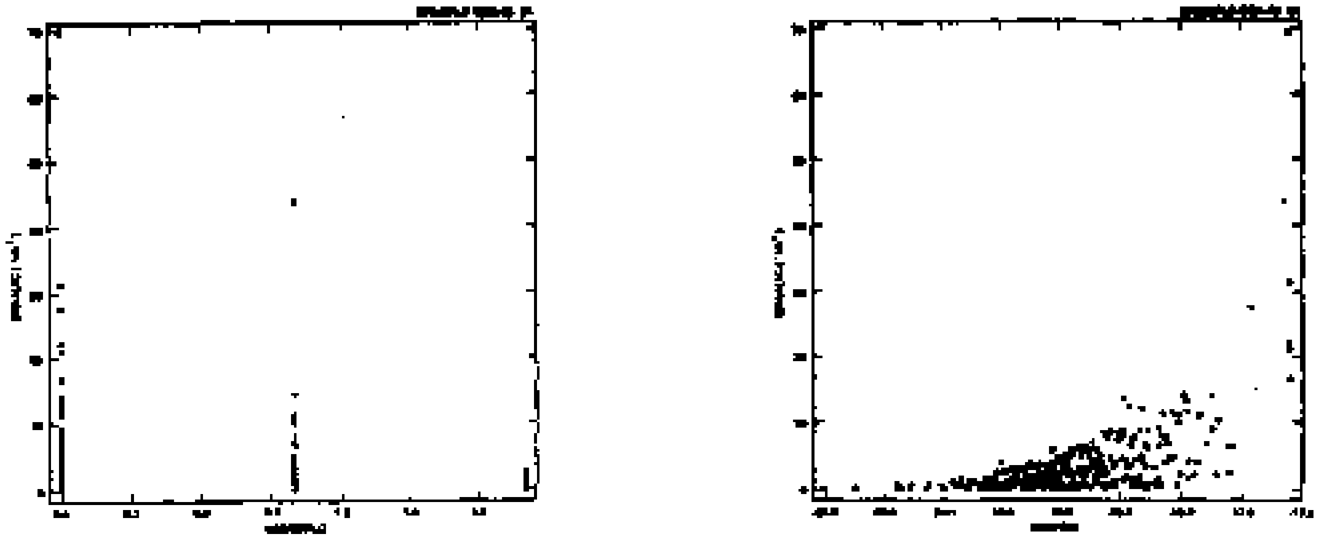


Fig. 2.1.4. Scatterplots for cumulative brine discharge (m^3) from the marker beds over 10000 yr under undisturbed conditions versus microbial gas generation flag (*WMICDFLG*) and marker bed permeability (*ANHPRM*, m^2).

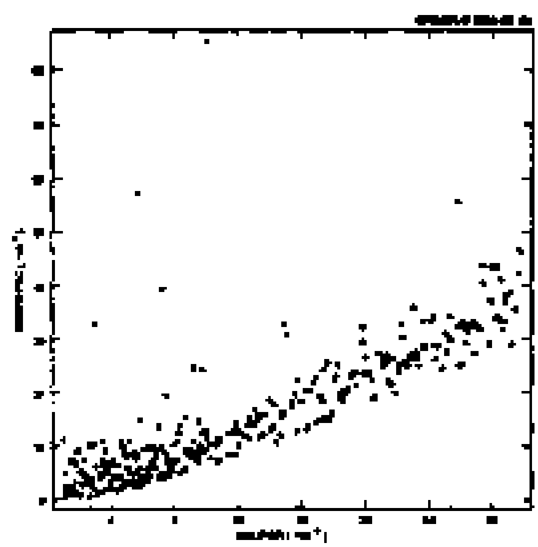


Fig. 2.1.5. Scatterplots for cumulative brine inflow (m^3) to the repository over 10000 yr under undisturbed conditions versus halite porosity (*HALPOR*).

From: Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

Figure 4

From: Vaughn, P., T. Hadgu, D. McArther, and J. Schreiber, FEP Screening Analysis S1: Verification of 2D-Radial Flaring Using 3D Geometry, Memorandum to D.R. Anderson, January 26, 1996.

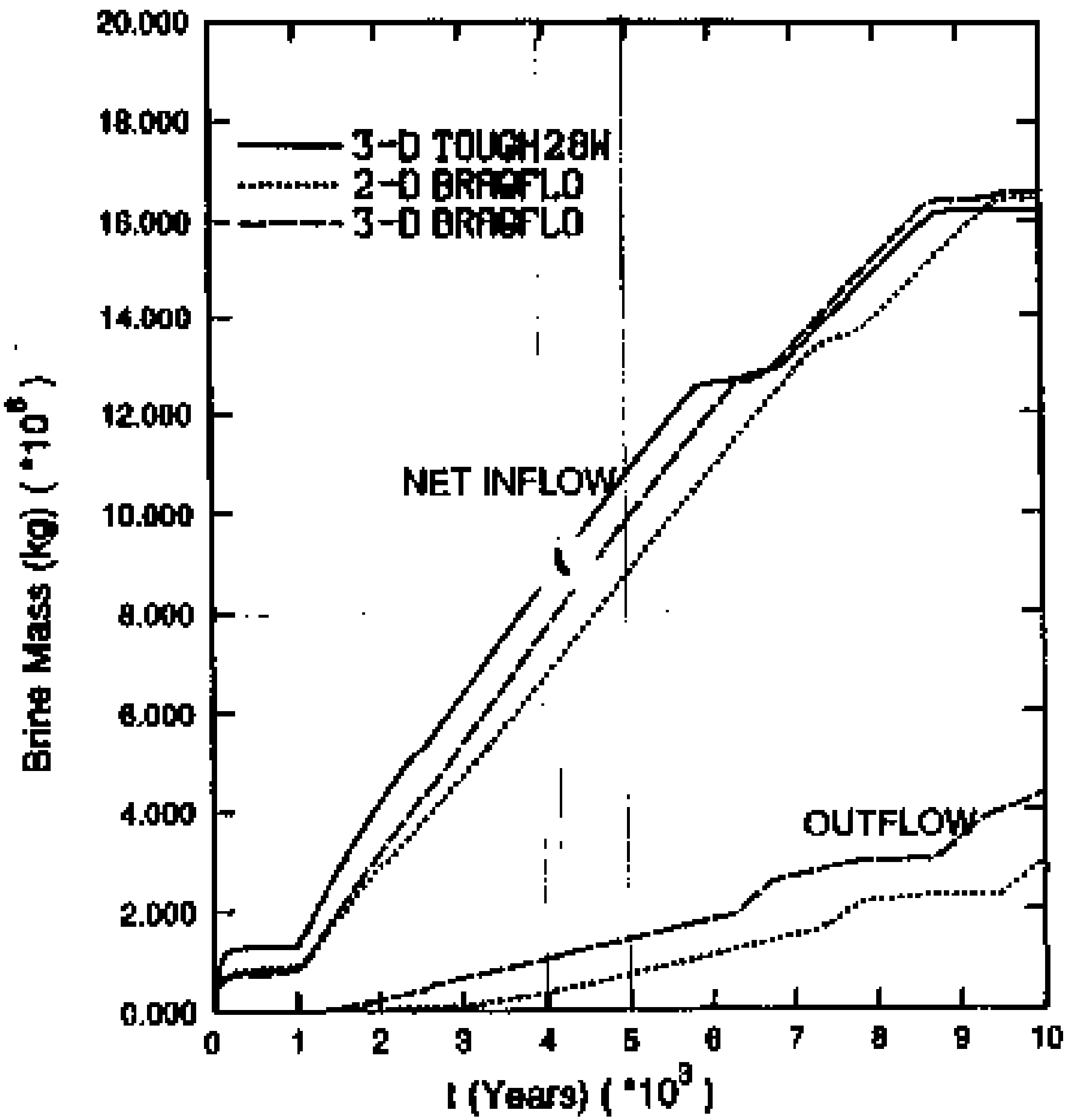


Fig. 10 Cumulative Net Brine In and Outflow at Repo. - Base Gas Generation rate

ERRATA

PROBABILITY OF MICROBIAL DEGRADATION

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[8] lists this parameter as the largest influence on the variation of total calculated release from the WIPP repository.

The documentation[9] 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. 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 judgement. 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.

The numerical values of the degradation probability parameter should undergo peer review consistent with expert judgement. Otherwise, the parameter should be conservatively set to always specifying microbial degradation of cellulose, plastics, and rubber.

---

[8]Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

[9]Wang, Y. and L. Brush, Estimates of Gas-generation parameters for the long-term WIPP performance assessment, Memorandum to M. Tierney, WPO 31943, January 26, 1996.

BOREHOLE PLUG LIFETIME

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 the release estimates.

Repository pressure is one of the key factors determining the severity of both spallings and direct brine release. The repository pressure decreases rapidly after the failure of the borehole plug from an initial human intrusion in BRAGFLO calculations of most of the sampled vectors[10]. Thus, the assumed lifetime of the borehole plugs may have a large impact on the final release estimates. The upper borehole lifetime is fixed at two hundred years in all of the BRAGFLO calculations, except for the continuous plug configuration. This conflicts with the data used to calculate the borehole lifetimes[11]. The analysis indicates that the results of investigation on corrosion and borehole lifetimes are expected to vary over an order of magnitude (Thompson, et al. page B1) and are considered to be conservative(Page B-17).

The calculation of upper plug lifetime is not entirely clear. It seems to rely on 1) an assumed corrosion rate of 1- 3 mm/year for steel casing 2) the assumption of sufficient water 3) field observations of casing failures in the Salado and 4) rapid degredation of the concrete plug after casing failure. The assumption of corrosion rate is stated to be "very aggressive" and conservative and about one thousand times faster than the corrosion rate in the repository. Short borehole plug lifetimes could be considered conservative for releases to the Culebra, but not for spallings and direct brine release to the surface. The general assumption of sufficient water is adequately justified in the analysis. However, the point is made that cement outside of the casing may inhibit access to brine(Page B-18). Field observations indicate that casing failures in the Salado are well-known (Page B-20; Bailey memo in La Venue, 1991[12]) at depths less than 1,000 feet. However, the same report(Page B-17) also includes information that casing failures in the Salado are common but not pervasive.

The borehole plug lifetimes are likely to vary by over an order of magnitude. Borehole plug lifetimes should be a sampled parameter.

---

[10] Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December 23, 1996.

[11] Thompson, T.W., W.E. Coons, J.L. Krumhansl, and F.D. Hansen. Inadvertent Intrusion Borehole Permeability, Attachment 16-3 in Appendix MASS of the Compliance Certification Application, DOE/CAO-1996-2184, October, 1996.

[12] La Venue, M. Anomalous Culebra water-level rises near the WIPP site, INTERA: Technical Letter Memorandum, January 28, 1991

INCONSISTENCY BETWEEN DIRECT BRINE RELEASE AND SPALLINGS GEOMETRY

The EEG considers the inconsistency in the conceptual models of direct brine release and spallings in the CCA calculations to be unacceptable. The transport of solids and brine to the surface as a consequence of human intrusion is a single process where both brine and solids are entrained in a high velocity gas flow. In our January 21st presentation to EPA, we argued that both brine and gas flow should be modeled as a single process.

The spallings model predicts that channels of void space will be created in a waste room as a result of room depressurization from drill penetration into the room. The channels develop because the velocity of gas is large enough to break the bond of particles from the compacted mass of waste and entrain them in the gas-flow down the channels. This process is aided by the flow of gas perpendicular to the channels. The solid mass calculated to have been released in the spallings model is assumed to evacuate an annular region around the borehole in the direct brine release model. Brine is calculated to be transported to the enlarged borehole region as described by Darcy's Law.

If open channels are created in the spallings process then pressure gradient will drive brine towards these openings. The distance to the open channels would be far less than the distance to the borehole for most of the brine in a waste room and all brine in other rooms of a repository panel. The cumulative release to the surface would, thus, be much larger than calculated by the direct brine release model.

Direct brine release and spallings should be modeled as a single process. If the process is separated into two models, these models must be consistent with each other.

WASTE PERMEABILITY VALUE FOR DIRECT BRINE RELEASE

Issue

The CCA uses a constant waste permeability value of 1.7×10^{-13} m^2 in the Direct Brine Release calculations. The method of calculating this value was questioned by a Peer Review Panel and DOE agreed that 2.4×10^{-13} m^2 was the appropriate value. The use of this higher value in CCA calculations is considered here.

The rate of radial flow to a well per unit drop in pressure or drawdown is directly related to the permeability of an aquifer. The same relation would apply to flow into a borehole that penetrated a waste storage room.

This discussion will not address other waste permeability related aspects of the Direct Brine Release, Spallings, or BRAGFLO Models such as relative permeability, residual brine saturation, and fracture flow.

Evaluation

SNL arrived at the value of 1.7×10^{-13} m^2 for consolidated waste from laboratory data on three major waste components (sludge, combustibles, and metals). The Engineered Systems Data Qualification Peer Review Panel discovered an error in the calculation of the overall permeability and, after discussions with SNL on the appropriate distribution to use on permeability values for each material, agreed with SNL that the appropriate calculated value should be 2.4×10^{-13} m^2.

The Peer Review Panel recognized that use of this higher permeability value would increase brine releases in direct proportion to the increase in permeability (41%). Yet they concluded that changing this value is not warranted because "the change does not have any effect on the final outcome," (page 9-191). The panel also opined that the data and assumptions that were used to develop the values were limited and either value was as good as the other.

Clearly there are uncertainties in the actual value of the consolidated waste permeability. There is also the question of whether the current assumption of darcy flow is appropriate or whether the rooms should be modeled as fracture flow. Neither issue is being addressed here.

Changes in the volume fractions of combustibles, metals, and sludges in the waste from the .40, .40, .20 values used in 1991 would also change this permeability calculation. The Final Waste Form volumes shown in Table 4-3 of the CCA are slightly different and result in a calculated permeability of 2.2^{-13} m^2.

Effect on CCA

The use of the higher waste permeability value (2.4×10^{-13} m^2) should cause the CCDF plot of direct brine release to move 41% towards the compliance limit. The CCDF plot in the CCA (Figure 6-41) shows direct brine release to be only 0.05 EPA units at .001 probability. Increasing this by 41% would give a value of only 0.07 units and would have little effect on compliance. However, other questions are being raised about these releases: (1) Castile Brine Reservoir assumptions; (2) appropriate solubility values to use; and (3) details about the Direct Brine Release Model. These other factors could increase the calculated release by more than an order-of-magnitude. If this occurs the 41% increase could become significant.

Recommendation

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.

RANDOM EMPLACEMENT OF WASTES IN REPOSITORY

Issue

In the CCA, DOE assumes that the waste inventory will be emplaced in the repository in a purely random manner. This assumption leads to three further assumptions in the CCA:

(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 also is calculated from the average of the entire WIPP inventory.

Evaluation

DOE correctly recognizes that the concentrations and radionuclides composition of individual waste containers vary widely and have attempted to account for this in the CCA by sampling on a volume weighted distribution on all 569 CH-TRU waste streams identified in the Baseline Inventory Report, Revision 2. This approach, if done properly, has the potential to fully capture the variability if emplacement is purely random.

EEG believes that actual waste emplacement may deviate substantially from random. This is due to three factors: (a) during the period that a waste room is being filled there is unlikely to be shipment of waste from all Generating Sites on a volume weighted basis. (b) waste being shipped from a Site in a TRUPACT II is unlikely to be representative of the entire site; and (c) wastes arriving on a TRUPACT-II trailer (e.g. 4 to 6 seven-packs of 55-gallon drums) from a site would be emplaced to gather. Its possible that as many as 1/3 of the 7-packs or Standard Waste boxes on a TRUPACT-II trailer would be stacked two-high in a waste room.

Examples of the deviations of average concentrations from individual sites from the total inventory average concentration are: (1) The Savannah River Site (SRS) average is 2.9 times the total average at 100 years; (2) Los Alamos National Laboratory (LANL) averages range from 1.3 to 1.8 times the total average from 100 years to 10,000 years; and (3) Rocky Flats (RFETS) averages range from 3.0 to 4.5 times the total average from 100 years to 10,000 years. Examples of variations within waste streams at a Site are: (1) 2,800 m^3 of residues at RFETS that are 3.3 times the Site average: (2) 60 m^3 of SRS waste that are 42 times the Site average; and (3) 850 m^3 at SRS that are 1.5 times the Site average.

Effect on CCA

In the 1991 Performance Assessment (SAND91-0893/2), Sandia National Labs (SNL) demonstrated that considering the effects of variable radionuclide concentrations in waste containers ("activity loading") resulted in normalized releases from cuttings and cavings to increase by a factor of about ten (at .001 probability) compared to using average activity in containers. SNL has used "activity loading" in PA methodology since that time and in the CCA, the sampling is on 569 waste streams for cuttings and cavings. There is no disputing the fact that sampling on activity levels will increase the calculated releases from cuttings and cavings for probabilities below about 0.5.

The radioactivity concentration and radionuclide composition of waste within a waste room or portion of a panel (i.e. the areas of influence for the spallings and Direct Brine Release calculations) would be expected to vary from the total inventory average. This variation would not be nearly as great as that expected between individual stacks of waste containers, but increases to several hundred percent of the average radioactivity concentration are clearly possible. The calculated releases from spallings at any intrusion time would be directly proportional to the radioactivity concentration.

The calculated radionuclide releases from Direct Brine Releases would depend on the concentrations of each radioactive element in solution. This concentration is dependent on the composition of individual radioisotopes in the waste. For example, in average SRS waste at 350 years the ^{238}Pu radioactivity is 75% of the total plutonium radioactivity compared to 11% of the total plutonium in the total inventory average. Thus, the radioactivity concentration of plutonium in solution would be higher for SRS waste at 350 years. Another example is concentrations of ^{233}U and ^{234}U. Appendix WCA of the CCA states the assumption that only 1% of dissolved uranium would be ^{233}U and ^{234}U, because in the total inventory these radioisotopes comprise less than 1 wt% of total uranium. However, data in the Baseline Inventory Report indicates that the 28,000 m^3 of stored CH-TRU at INEEL contains 20 wt% of ^{233}U.

These concerns of non-uniform emplacement of wastes in the repository touch on the issue of load management. The CCA concludes that load management is not necessary at WIPP (Chapter 4.3.1).

Importance to Compliance

EEG believes that deviations from the assumption of average emplacement has the potential to increase calculated releases at .001 probability from spallings and Direct Brine Release by several fold. Using a more conservative assumption of random emplacement may not result in non-compliance if all other assumptions in the CCA were held constant. However more conservative assumptions could noticeably shift the CCDF curve toward the compliance boundary and, when incorporated with other changes to the 10/96 CCA, calculations could have a significant effect on the final CCDF.

Recommendations

For the Spallings and Direct Brine Release scenarios, determining average waste concentration in one room would be closer to reality compared with using the average for the whole repository as currently used in the CCA. There are several possible approaches to determining justifiable waste room radioactivity concentrations. We recommend the following:

(1) The deviation from average concentrations of radionuclides in waste and brine could be mitigated by load management such that the concentrations in any waste room be limited to (say) 1.5 or 2 times the average at any time during the 10,000 year regulating period;

(2) A reasonable upper bound (not the theoretical maximum) for radionuclide concentration can be obtained by assuming that a room is filled entirely with average concentration waste from the generating site that results in the greatest consequences. For concentrations in the waste this would be RFETS. It is not obvious which site's waste would result in the highest brine concentration.

(3) Allow DOE to show by an appropriate statistical scheme that there is an acceptably low probability that concentrations in wastes and brine will not exceed (say) 1.5 or 2 times the average;

(4) Actually sample on this variability. Sampling might be first on the fraction of waste from each site that is brought into the room (with some deviation above and below the actual fraction of the total repository volume expected from that site). Then the variation of waste composition and concentration from each site (obtained from the 569 waste streams data) could be sampled on.

For the cuttings and cavings calculation DOE should determine an appropriate statistical scheme to evaluate the effect that emplacing wastes from individual sites in clusters will have on the current calculations involving sampling on 569 waste streams. If significant these new values should be incorporated into the CCA.

RESIDUAL BRINE SATURATION OF WASTE

The preliminary sensitivity analysis report[13] indicates (Table 5.3.3) that the calculated releases to the surface from the direct brine release model are most sensitivite to the sampled variation of the waste room residual brine saturation. For various reasons the direct brine release model may be significantly under-predicting releases. See, for example, the EEG position statements on the brine reservoir parameters, solubilities, sampled parameters and probability of microbial degredation. The sampled range of the waste room residual brine saturation is another one of those reasons.

The data and rationale for the sampled distribution of the waste-room residual-brine saturation is presented on pages PAR-27 through PAR-31[14]. The recommended distribution is uniform from 0 to 0.56. It is stated in the data section that the parameter values are based on literature values of unconsolidated materials. Ten materials are listed as the source of the data set. Eight of these data values are from unconsolidated materials with a range of 0.0783 to 0.277. Two of the source materials are consolidated sandstones with values of 0.243 and 0.560. As suggested in Appendix PAR, the sampled range should be based on unconsolidated materials. Use of the single consolidated sandstone value of 0.56 doubles the range of sampled values in a non-conservative direction.

The non-conservative distribution of 0 to 0.560 reduces the estimated releases of direct brine release. 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.

---

[13] Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

[14] Appendix PAR of the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, DOE/CAO-1996-2184, December, 1996.

Environment Evaluation Group Review of the WIPP-CCA, 3/14/97

COMPENDIUM OF DIRECT BRINE RELEASE PROBLEMS

We have organized our comments on the CCA in a format so that individual sections tend to focus on single issues. To keep the individual sections brief, we have only occasionally touched on interrelationships between issues. In the case of the direct brine release model, we have found so many interrelated problems that it is worth bringing them together in a separate section. The issues raised in this section are discussed in more detail in their separate sections. The purpose here is to highlight how they have compounding effects on the direct brine release calculations.

We have identified nine separate issues that effect the direct brine release calculations. The issues are:

- Probability of microbial degradation
- Borehole plug lifetime
- Brine inflow from Salado: 2-D versus 3-D geometry in BRAGFLO
- Brine reservoir assumptions in the CCA
- Inconsistency between direct brine release and spallings geometry
- Waste permeability
- Residual brine saturation of waste
- Random emplacement of wastes in the repository
- Plutonium Solubility

Probability of microbial degradation

Direct brine release will only occur if the repository pressure is over 8MPa at the time of drilling intrusion. Above a pressure of 8 MPa, the magnitude of release is more strongly related to waste room saturation. Waste room saturation is dependent on the amount of brine entering the repository and on the repository pressure because the pore space is a function of pressure. The most important sampled parameter effecting repository pressure is microbial degradation. The microbial degradation assumptions are not defensible and may lead to a severe under prediction of the probability of greater than 8 MPa pressure and anhydrite fracturing.

Borehole plug lifetime

Borehole plug lifetimes were not sampled in the CCA analysis, so this parameter does not show up as important in the statistical sensitivity analysis. However, inspection of disturbed scenario pressure histories and the importance of borehole permeability are clear indications of the importance of plug lifetime. Borehole plug lifetimes are uncertain and the description of the development of this parameter in the CCA documentation indicates that the parameter is biased toward short plug lifetimes in an attempt to be conservative. Short plug lifetimes may lead to an under-prediction of the period of high pressures and, hence, may actually be non-conservative.

Brine inflow from Salado: 2-D versus 3-D geometry in BRAGFLO

The importance of anhydrite fracturing to direct brine release is under-represented in the CCA modeling. A full 3-D representation of the repository indicates that substantially more brine will enter the repository if the anhydrite beds open as a result of high pressures compared to brine-inflow under lower pressure conditions. The pseudo 3-D model used in the CCA analysis predicts the opposite. The highest direct brine release predictions occur with repository pressures below the initiation of anhydrite fracturing because of concurrent low brine saturation conditions. This is most likely in error.

Brine reservoir assumptions in the CCA

The DOE has admitted to the conceptual models peer review panel and in post application documents that the Castile brine reservoir parameters are incorrect. The use of these parameters in the CCA calculations severely under-predicts the importance of the Castile brine under the repository. In addition, the likelihood of intercepting Castile brine under the repository is reduced from a certainty to eight percent. Proper incorporation of the Castile brine reservoir in the CCA analysis will lead to higher brine saturations and most likely longer periods of pressures above the 8 MPa threshold.

Inconsistency between direct brine release and spallings geometry

We have identified three flaws in the actual direct brine release model. The most significant of these is the inconsistency of the void geometry of the spallings model to that assumed in the direct brine release model. The spallings model predicts the development of void channels throughout the room penetrated in a drilling intrusion. The direct brine release model assumes that all of the solid material entrained in the room depressurization has come from a annular region about the borehole. The geometric inconsistency could have a very large impact on calculated brine releases.

Waste permeability

The second flaw in the direct brine release model is a calculational error on the part of DOE. The waste room permeability value used in the direct brine release calculation is in error by 41%, based on the data used by DOE. This error leads to a 41% bias to low values in the calculated releases.

Residual brine saturation of waste

The calculated flows are also biased by using a distribution of residual brine saturations that is unrealistic. Brine moves much slower if the saturation is near or falls below the residual saturation level. Residual saturation is twice as high in the CCA calculations than can be supported. This reduces both the frequency and magnitude of the estimated releases to the surface.

Random emplacement of wastes in the repository

The CCA calculations ignore the possibility of higher consequence events due to non-uniform distribution of waste emplacement. In the direct brine release calculations the actinide content of waste in a room is assumed to be the average of all waste. In practice waste will tend to be grouped by origin and to a degree the waste steams. This would result uncertainty in the radionuclide concentrations in a room's brine content and higher releases in some instances.

Plutonium Solubility

Finally, the importance of brine release to the surface is under-represented in the calculations because of the low assumed values of plutonium solubility, especially in the case of releases subsequent to an interception of Castile brine. The difference in plutonium solubility in the Castile brine become important to calculations that include a proper representation of the Castile brine.

Of these nine problems in the direct brine release calculations, probably only the inconsistency in the direct brine release model geometry has the potential to shift the release calculations to the release criteria values. When considered together, it is clear that radionuclide transport to the surface through brine transport is potentially a much larger threat to safety than predicted in the CCA calculations and could be a much larger concern than the current predictions of release of solids to the surface.

ACTIVE INSTITUTIONAL CONTROL

The DOE conducted an elaborate elicitation exercise in 1990 to address the issue of future inadvertent human intrusion into WIPP (Hora et al., 1991). Members from each of the four “futures teams” expressed reservations about the ability of the project to fully maintain active control for even a very short period of time. Participants in the elicitation exercise were asked to address seven specific issues including the issue of active controls:

> Assuming that the radioactive waste exists and is harmful, what is the likelihood that active controls (continued management of the site) have been maintained to prevent inadvertent intrusions? (Hora et al., 1991, p. G-4).

Three of the four members of the Washington A Team predicted a steep decline in the probability of active controls as a function of time beginning immediately after closure (Hora et al., 1991, Figure IV-10). At 100 years after closure, they predicted the probability of active control for all four postulated future states at less than 30%. The fourth member also predicted an immediate decline, although at a slower rate, in the probability of the effectiveness of active control after closure (Hora et al., 1991, Figure IV-11). In summary, the Washington A Team predicted less than 100% active institutional control for the first 100 years beginning immediately after closure.

The Washington B Team assigned probabilities that the government would continue to maintain prudent and effective control over the WIPP. They defined the near future as 0-200 years after closure (Glickman et al., pp. F-4, F-27; Hora et al., 1991, p. IV-55). This team questioned the effectiveness of active control for the near future and assigned a probability of 80% for prudent and effective control for the near future (Hora et al., 1991, pp. IV-55-56).

Hora stated that the Boston Team allowed for 100 years administrative control (Hora, 1992, p. A-87). However, scrutiny of the Boston Team report (Gordon et al., 1991) and the report by Hora et al. (1991) suggests otherwise. It appears that the input was adjusted to fit the needs of the performance assessment calculations as explained below. This adjustment, and not the Boston Team, allowed for 100 years administrative control.

The Boston Team did not offer direct estimates of the duration of active institutional control. Rather, the Boston Team predicted socio-technical factors at 100 years, 1000 years, and 10,000 years (Gordon et al., 1991, p. C-5); points in time were incompatible with the needs of performance assessment. As noted by Hora et al. (1991, p. IV-3) "...the performance assessment calculations require rates of intrusion during the entire continuum from 100 to 10,000 years after closure." Thus, the use of midpoints on the logarithmic scale was introduced to define time periods. For example, the 100 year point was converted to a period of 0 to 300 years after closure (Hora et al., pp. IV-3 to IV-4). The first 100 years were then dropped and the results of the elicitation for ten tables were presented for time periods from 100-300 years (Hora et al., 1991, Tables IV-2 through IV-11) and not from 0-300 years. However, Table IV-14 (Hora et al., 1991) presents the calculated drilling rate probability for 0-300 years after closure. This table suggests that the Boston Team did not allow for 100 years administrative control.

Moreover, one member of the Boston Team disputed the existence of administrative control for even a short period of time. In an appendix to the Boston Team report (Gordon et al., 1990), Baram addressed the question "Can memory of WIPP be retained?" Rather than argue in the abstract, he cited examples of the factual loss of history or active control for periods shorter than 50 years. The examples included:

1) the loss of drilling history at Lyons, Kansas that was fortuitously recaptured by opponents to a proposed repository at that location,

2) the loss of information for 45 years on the dumping of barrels of radioactive waste from the Manhattan Project in the late 1940's by the Department of Defense at the Massachusetts Bay site,

3) the unavailability of information until 1986 on the release of radiation and exposure of thousands of people near Hanford beginning in 1944,

4) the use of uranium mill tailings in Colorado to construct homes and other concrete structures despite a prohibition against such activity,

5) the 1982 sewer line construction and inadvertent intrusion into a poison gas container abandoned by the Army when it closed an airfield in 1945.

"The [Southwest] team was fairly pessimistic with respect to society's ability to maintain active controls and effective markers" (Hora et al., 1991, p. IV-31). One member speculated that controls and markers may last as long as 1,000 years, two members felt that loss would likely occur within hundreds of years, and one member thought loss of markers and active control would occur in less than 100 years.

Thus, all four teams in the elicitation exercise on future societies expressed reservations about the project's ability to maintain active control for even a short period of time.

EEG recommends that the EPA should initially assume zero credit for active institutional and ask DOE to cite specific tangible factors as to how much credit can be justified. 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 control.

References

1. Hora, S.C., von Winderfeldt, D., and Trauth, K.M., 1991. Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant. SAND90-3063. Sandia National Laboratories.

2. Glickman, T., Singer, M., Rosenberg, N., Vinovskis, M., 1991. The Report of the Washington Area Second Team on Future Inadvertent Human Intrusion into the WIPP Repository. Appendix F to SAND90-3063. Sandia National Laboratories.

3. Hora, S.C., 1992. Probabilities of Human Intrusion into the WIPP Methodology for the 1992 Preliminary Comparison, August 25, 1992. Appendix to SAND92-0700, pp. A-69 to A-99.

4. Gordon, T.J., Baram, M., Bell, W., Cohen, B., 1990. Inadvertent Intrusion into WIPP: Some Potential Futures. Appendix C to SAND90-3063. Sandia National Laboratories.

PASSIVE INSTITUTIONAL CONTROL

The CCA claims that passive institutional control will be 99% effective in deterring drilling into the repository from 100 years to 700 years after closure. The components of passive institutional control include government ownership, records, and markers. Based on the 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.

Government Ownership and Regulation

With respect to the government ownership, the DOE maintains that "the controls that are crucial to protect the site from inadvertent exploration are BLM leasing procedures and lease records and the internal procedures of the BLM which require the DOE's review and comment for any permit application to drill within one mile of the WIPP site."[1] On October 26, 1990, the DOE and the DOI/BLM signed a Memorandum of Understanding. With respect to drilling for oil and gas, the MOU specifically required the BLM to notify the DOE of applications for permit to drill for oil and gas within one mile of the WIPP Site Boundary and that "drilling approval will be withheld until comments are received from the DOE."[2] The MOU was revoked on October 30, 1992 with the passage of the 1992 WIPP Land Withdrawal Act[3] (Section 3 (b)). How effective was the MOU for that two year period? The following example is fairly typical of the overall failure of the MOU.

The BLM approved an application to drill Well #4, Section 26, T22S, R31E, on October 15, 1991. Two days later, the BLM[4] sent a letter to the DOE requesting a review of an "Application for Permit to Drill" within one mile of the WIPP Site Boundary. The BLM received DOE's review[5] on October 25, 1991. However, not only had the application already been approved by BLM ten days earlier, but drilling had already commenced the previous day. Thus, the DOE's review was never considered in the application permitting process, the DOE review was not solicited until after the drilling had been approved, and the DOE review was not received by BLM until after drilling had started.

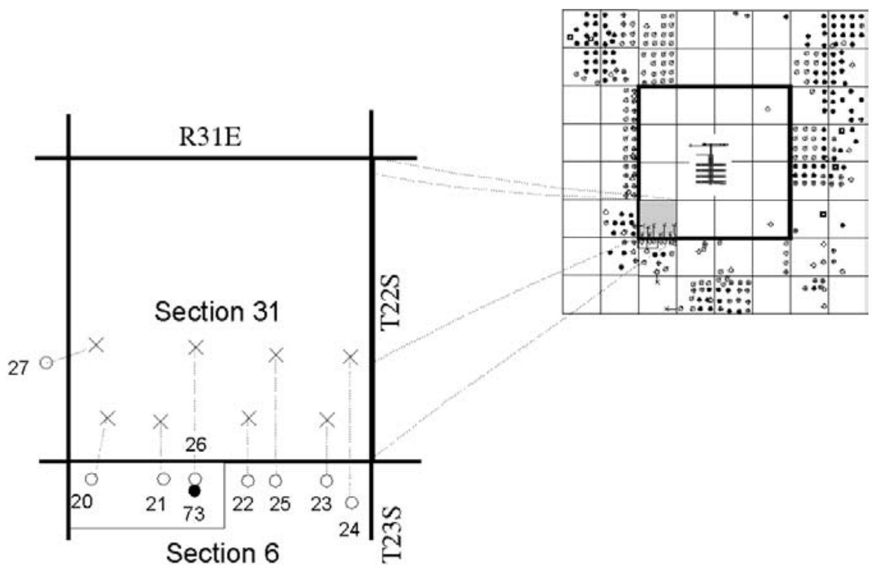
Table 1. Summary of Lapses in Institutional Control

Satisfactory procedure	3
BLM failed to request DOE review.	3
DOE failed to respond to BLM request.	9
BLM approved permits to drill before requesting DOE review.	5
BLM approved permits to drill before receiving DOE review.	5

The MOU failed in twenty-two out of twenty-five applications for an institutional failure rate of 88%. EEG notified DOE of this lapse in institutional control in 1993[6,7]. Fifty-five subsequent applications, processed through July 1994, showed a failure rate of 9%.

Records

A recent example illustrates the failure of records to communicate important information prohibiting drilling in a certain area. In 1978, the DOE purchased leases in the vicinity of the current WIPP site for the explicit purpose of preventing drilling. One area was the N½ NW¼ of Section 6 T23S, R31E (eighty acres) for which the DOE paid Bass Enterprises et al. $207,972 not to drill through the uppermost 6000 feet[8,9].



In April 1993, Bass Enterprises et al. applied to the BLM to directionally drill eight wells from Section 6 locations outside the WIPP Site to their oil and gas lease reserves 6000 feet below the WIPP Site. In August 1994, the BLM denied the drilling applications citing the WIPP Land Withdrawal Act.[10] In January 1995, Bass et al. filed a claim in federal court for a takings.[11] In June 1996, the federal court awarded Bass et al. $8.9 million plus interest.[12]

Despite the active involvement of attorneys and officials for the oil companies and four federal agencies (DOE, BLM, EPA, and the Justice Department), the 1978 judgment, forbade drilling wells in Section 6 T23S, R31E, was not discovered until after the June 1996 judgment.[13,14,15] (Refs. 14 and 15 attached). Subsequent appeal by the Justice Department states:

> Among the issues that could be addressed on remand are the implication of the discovery, made after the notice of appeal was entered in this case, that Bass did not have the right to drill from three of the locations from which it proposed to drill — and for which it sought and received compensation — because DOE had

condemned those surface locations in 1977.[13]

Hence, in less than twenty years, records failed to communicate important information concerning the restriction against drilling for oil and gas. Furthermore, a vertical gas well, James Ranch Unit 73, was drilled and completed on the eighty acres in July 1996 prior to the discovery of the lease records by the attorneys for the various federal agencies.

Markers

"Any compliance application shall include the period of time passive institutional controls are expected ***to endure*** and be understood."[16].

On October 26, 1963 a twelve kiloton device was detonated underground at Fourmile Canyon, Nevada. The site was designated as the Shoal Site. In the late 1970's the DOE placed a substantial marker consisting of a brass plaque set in a concrete podium and anchored to a concrete base at ground zero. By 1985, the marker at the Shoal site had been completely destroyed by a massive explosion with pieces of marker scattered to the west. The brass plaque had disappeared. Shown below are the gathered remains of a DOE marker intended to identify an area contaminated by radioactive fission products. This marker lasted less than ten years. This example raises questions on the DOE's commitment to maintain a marker at WIPP.

Recommendation
EEG recommends that the EPA include full consideration of these lapses in the assessment of the DOE's claim of 99% effectiveness of passive institutional controls from 100 to 700 years after closure.

References

1. Arthur, W.J., 1992. November 3 letter from the WIPP Project Director to R.H. Neill, Director of the Environmental Evaluation Group.

2. U.S. Department of Energy/U.S Department of Interior, Bureau of Land Management. October 26, 1990 Memorandum of Understanding cited by the 1991 Administrative Land Withdrawal, 43 CFR Public Lands Order 6826, January 22, 1991.

3. U.S. Congress, 1992. Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579, 102d Congress.

4. Manus, R.L., 1991. October 17 letter from BLM Carlsbad Resource Area Manager to A. Hunt, DOE WIPP Project Manager.

5. Becker, R.M., 1991. October 23 letter from DOE Repository Technology Group to R.L. Manus, BLM Carlsbad Resource Area Manager.

6. Neill, R.H., 1993. March 9 letter from the Director of the Environmental Evaluation Group to W.J. Arthur, WIPP Project Director.

7. Neill, R.H., 1993. May 26 letter from the Director of the Environmental Evaluation Group to A. Hunt, WIPP Project Manager.

8. McGough, J. M., 1981. December 30 letter to G. B. Koski, Area Manager, U.S. Bureau of Land Management, Carlsbad Office.

9. Silva, M.K. and Channell, J.K., 1992. Implications of Oil and Gas Leases on the WIPP on Compliance with EPA TRU Waste Disposal Standards. EEG-50.

10. Calkins, W.C., 1994. August 22 letter from the U.S. DOI/BLM State Director for New Mexico to Keith E. Bucy of Bass Enterprises Production Company.

11. Bass Enterprises Production Company et al., 1995. January 23 Complaint for a taking in violation of the U.S. Constitution. Case 95-52L, U.S. Court of Federal Claims, Washington D.C.

12. Hodges, R.H. Jr., 1996. June 20 Judgment of the United State Court of Federal Claims. 95-CV-52.

13. Schiffer, L.J., 1996. Appeal from a judgment of the United States Court of Federal Claims in 95-CV-52 entered June 21, 1996, Judge Robert H. Hodges, Jr.

14. Neill, R.H., 1997. January 3 letter from the Director of the Environmental Evaluation Group to Susan Cook, Attorney for the U.S. Justice Department.

15. Martin, M.K., 1997. February 13, 1997 letter from Attorney for the U.S. Justice Department to R.H. Neill, Director of the Environmental Evaluation Group.

16. U.S. Environmental Protection Agency, 1996a. 40 CFR Part 194, Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, Final Rule. Federal Register (9 February) vol. 61, no. 28, 5224-5245.

POTASH MINING

The CCA underestimates the areal extent of potash reserves and the potential impact of the mining of potash within the site and on adjacent federal and state properties. The use of only the existing leases adjacent to the site does not account for the currently economical potash reserves. Figure 1 shows the extent of lease grade potash ore as determined by the Department of Interior. Further, the Department of Interior notes that potash ore has been and can be economically mined at ore concentrations less than current lease grade[1].

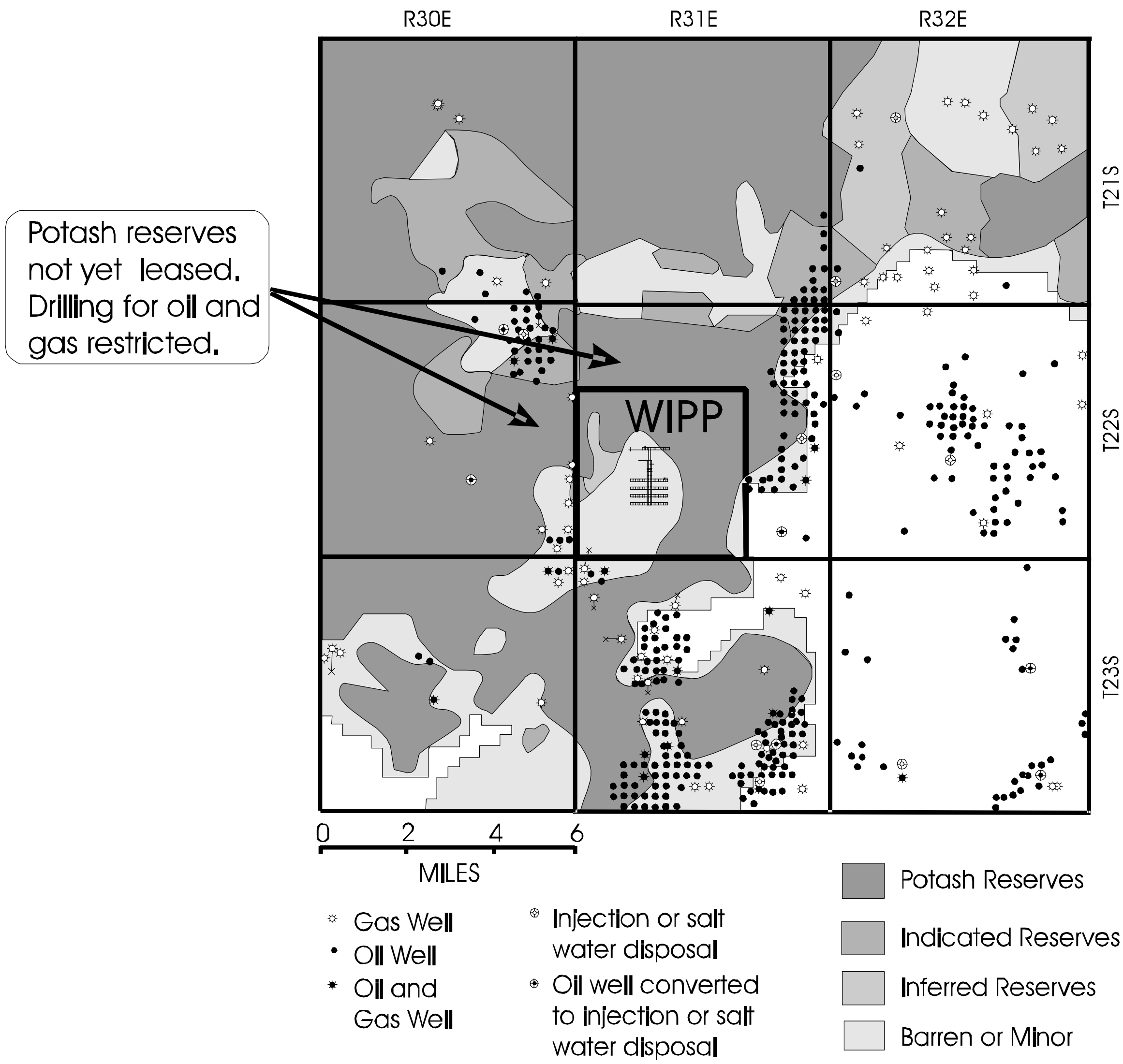


Figure 1. Lease grade potash ore[2] and oil and gas wells.[3]

For illustrative purposes, Figure 1 identifies one area of known potash reserves adjacent to the northwest boundary of the WIPP Site. Figure 2 indicates that these potash reserves have not been leased. Potash operators are allowed to hold, directly or indirectly, no more than 51,200 acres in potash permits and leases in a state (43 CFR 3530.3). An operator may not hold all the potash leases he intends to develop (Ref.4, p. 11).

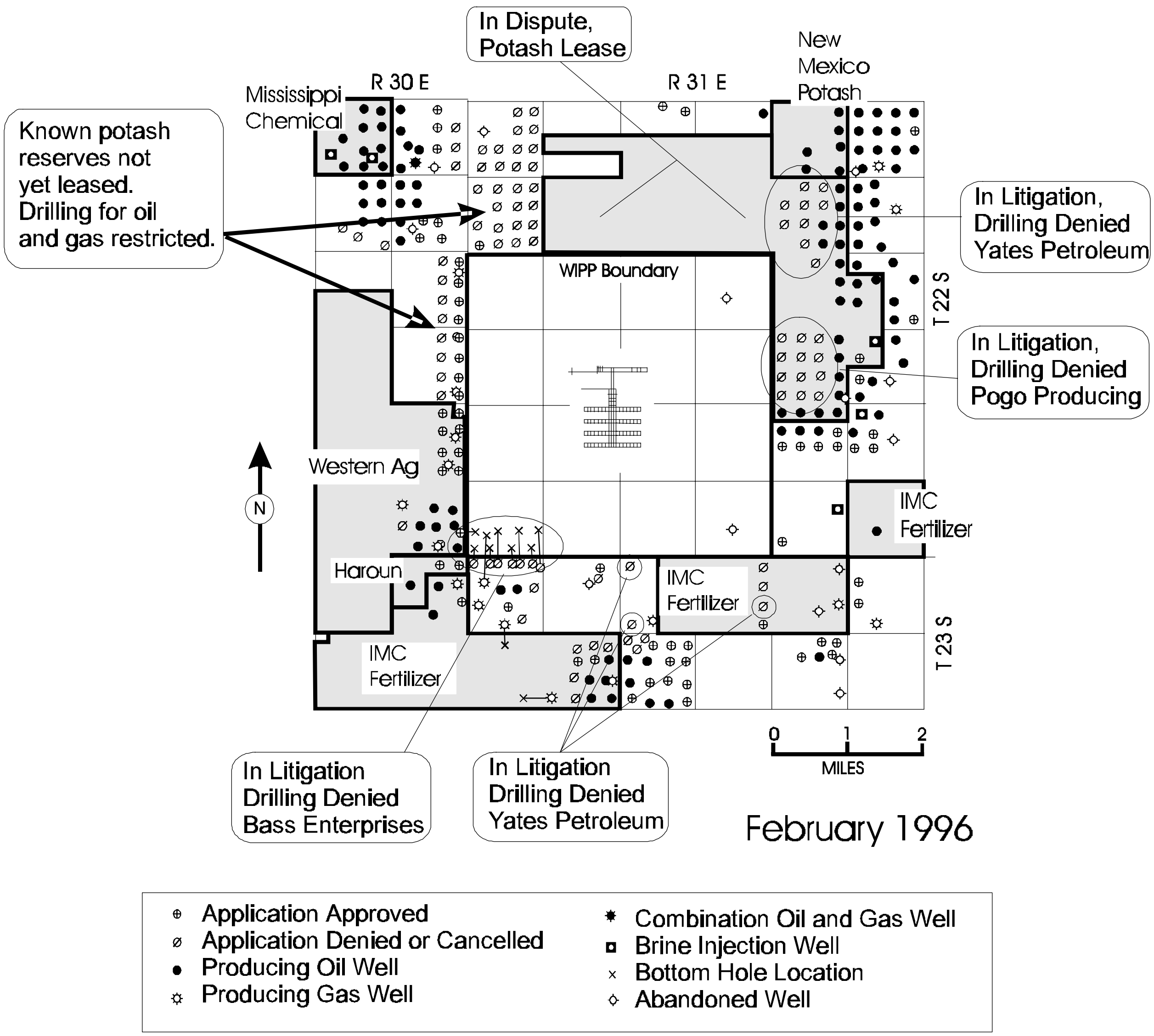


Figure 2. Drilling for oil and gas restricted by BLM due to the presence of potash reserves, leased and unleased.

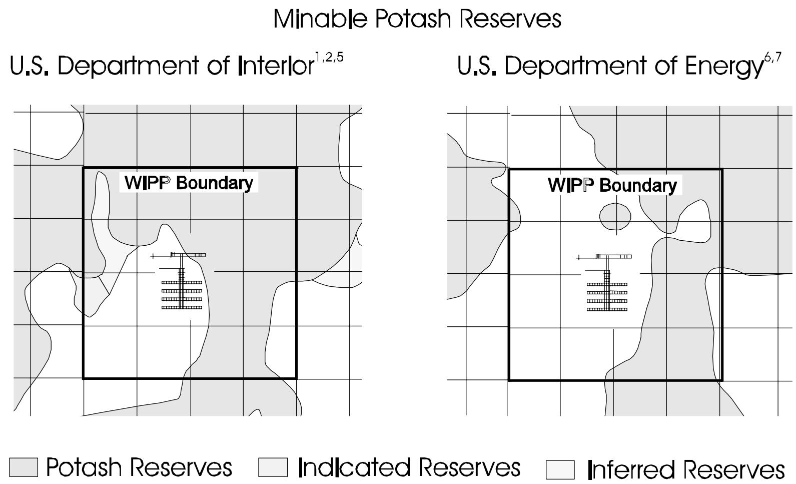


Figure 3. Minable potash.

Figure 3 shows the different estimates by DOE and DOI of the extent of minable potash within the WIPP site.

As shown in Figure 4, the CCA does not include the impact of potash mining in unleased areas which will also affect the regional hydrology. 40 CFR Part 194.32 states:

> Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur.

EPA's Compliance Application Guidance for 40 CFR Part 194 (p. 46) states:

> EPA recommends that DOE use minable reserves in estimating mine linve and the extent of potential mining.

The Use of only the existing potash leases does not therefore satisfy the EPA's intent.

Limiting the CCA to "near future" resource recovery activities appears to be inconsistent with the Federal Land Policy and Management Act[7] and limiting the CCA to "exisiting leases" does not reflect anticipated mining. All federal public lands, including those adjacent to the WIPP Site, are "to be managed in a manner which recognizes the nation's need for domestic sources of minerals, food, timber, and fiber...." (Ref.8, §1702(12)). In addition, FLPMA requires the management of federal lands "be on the basis of multiple use and sustained yield unless otherwise specified by law" (Ref.8, §1701(7)). "The term multiple use means the management of the public land and the various resource values so that they are utilized in the combination that will best meet the present and ***future needs*** [emphasis added] of the American people" (Ref.8, §1702(c)). The term multiple use also means "a combination of balanced and diverse resource uses that take into account the ***long-term needs of future generations*** [emphasis added] for renewable and nonrenewable resources.... Sustained yield is defined as "the achievement and management ***in perpetuity*** [emphasis added] of a high-level annual or regular periodic output of the various

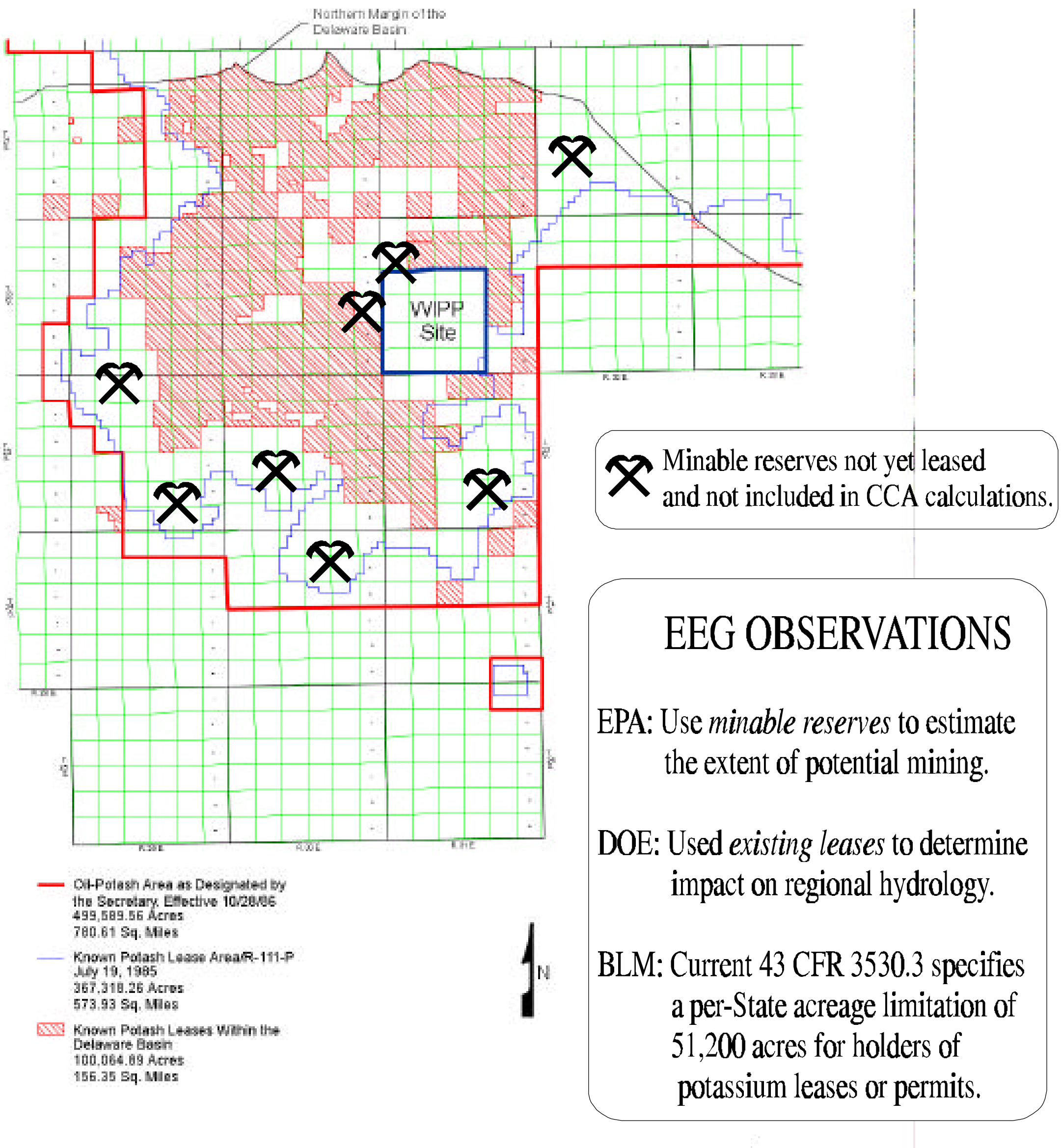


Figure 4. Potash leases within the Delaware Basin and minable potash not yet leased.

renewable resources of the public land consistent with multiple use" (Ref.8, §1702(h)). Human activities in the resource rich areas surrounding the WIPP are not limited to the ***near future*** and are not limited to ***the expected use of existing leases***.

The objectives of the state are also "to prevent waste, protect correlative rights, assure maximum conservation of the oil, gas and potash resources of New Mexico, and permit the economic recovery of oil, gas, and potash minerals..." (LeMay et al. 1988).

Recommendation

EEG recommends that the CCA consider all minable potash resources, as specified by the BLM, in the performance assessment calculations.

References

1. Cone, L.M., 1995. Oct 12 letter from U.S. DOI/BLM District Manager to G.B. Griswold.

2. U.S. Department of Interior, 1993. Preliminary Map Showing Distribution of Potash Resources, Carlsbad Mining District, Eddy and Lea Counties New Mexico By Bureau of Land Management, Roswell District.

3. Broadhead, R.F., F. Luo, and S.W. Speer, 1995. Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Carlsbad, NM: Westinghouse Electric Corporation, Waste Isolation Division. Vol. 3, Chapter XI.

4. Vaughn, G.L., 1995. December 13 Agency Answer to Appellant's Statement of Reasons by U.S. Department of Interior Bureau of Land Management General Counsel. Yates et al., appellants. IBLA 92-612.

5. Griswold, G.B., 1995a. Method of Potash Reserve Evaluation, In Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Carlsbad, NM: Westinghouse Electric Corporation. Waste Isolation Division, vol. 2, Chapter VII.

6. Griswold, G.B., 1995b. October 16 letter to J. Barker, of the New Mexico Bureau of Mines and Mineral Resources, P. Anselmo of the New Mexico Institute of Mining and Technology, W. Thayer of IMC Corporation, and S. Patchet of Westinghouse Waste Isolation Division.

7. U.S. Department of Energy, 1996. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant. DOE/CAO-1996-2184.

8. Federal Land Policy and Management Act of 1976. U.S. Code Annotated, 1989. vol. 43, secs. 1701-1784.

DOCUMENTATION OF FEPs AND PARAMETERS

In reviewing the CCA, assumptions concerning the features, events, and processes (FEPs) used in performance assessment (PA) and parameters used by the computer modeling should be checked to ensure that supporting documentation is valid. Due to limitations in manpower the EEG has not made as extensive effort to investigate the DOE's documentation of its efforts in these areas as has the EPA. However, in conjunction with various EPA efforts at SNL since the publication of the CCA, the EEG has investigated a small sample of both parameters and FEPs. This sample shows that there is cause for concern about the records available for both FEPs and parameters. In brief, three of the four parameters examined showed what seem to be significant problems for CCA documentation; and FEPs screening activities are dominated by what appears to be significant omissions and errors.
The information below may no longer be current, as SNL attempts to improve the documentation as feedback from the EPA is received. The attempt here is to show the types of problems that were in the documentation at the time the CCA was submitted.

CCA Appendix PAR Values Differ from PA Code Values

The parameter database used to construct Appendix PAR is different than the parameter database used by the computer codes at the time PA analysis for the CCA was performed. A later version of the parameter database, in which different values for some of the parameters had been added, was used for Appendix PAR, according to SNL personnel.

Table PAR-12 in the CCA shows Parameter ID # 3148, bulk compressibility (COMP_RCK CONC_PLG), to have a value of 1.2E-09 Pa^{-1}, whereas the value used in the CCA PA calculations was 2.64E-09 Pa^{-1}. Supporting documentation (Form 464s in WPO # 36591) indicates the value was 0 Pa^{-1} from March 14, 1996, to May 2, 1996, when it was changed to the 1.2E-09 Pa^{-1} value. The 264E-09 Pa^{-1} value apparently preceded the March 14, 1996 date. This implies that the parameter database used in the CCA PA may have preceded the March 14, 1996 date.

A June 17-21, 1996, CAO audit of SNL (A-96-03) discovered that many parameters had been entered into the database without following proper procedure, which included not only completion of records but also required reviews and sign-offs before entry into the database. The list of such parameters eventually grew to more than 230 (out of 1500 total parameters). If the CCA PA was using a database established prior to corrective actions for these parameters then the parameters may not have been properly qualified for use.

Documentation of Supporting Information for Parameters

Form 464s are the records that establish and justify values for parameters that are to be entered into the database used by PA analyses. The Form 464s either show justifications directly or provide information which allows tracing of the values to supporting data and analyses. For the

Castile Brine Reservoir Pressure parameter (WPO #31612), successive Form 464s may be used to illustrate the sorts of problems encountered in tracing values used for parameters.

The later of two Form 464s in the data package changes the distribution "Type" of the earlier Form 464 from "cumulative" to "triangular", which changes the method of calculating the uncertainty distribution from the median value to the mode. The use of the median value (cumulative distribution) is supported in 5 pages of information attached to the earlier Form 464, but the later Form 464 merely announces the change to the mode (triangular distribution) without justifying it. The only documentation for the change is the statement under "Interpretation" on the later Form 464:

> The mode is entered into the database in place of the median. The median was calculated and is 13.4E+06 Pa.

Apparently, the mode value was erroneously placed into the database as a median, because the mode value had been erroneously entered on the earlier Form 464 in the median block. On discovery, the solution was to use a new Form 464 to change the type of distribution so that the mode value already in the database would match the Form 464, rather than change the value in the database to the correct median value. The result appears to be that an unsupported value of 2.17E+07 Pa is in the database instead of the supported value of 1.34E+07 Pa.

The support information for the Form 464s shows additional problems. Attached to the 464s is a document entitled "Original Interpretation (1/12/96)", which includes a table of data that:

> ...defines a cumulative (empirical) distribution based on the 8 data points for pressure mentioned in the source document (SWCF-A:1.2.07.1: PDD: NON-SALDO: PKG # ?: Castile Brine Reservoir)
>
> The weights to be given to the 8 values of pressure were specified by author of source document.

The 8 pressure data point values are copied into a second table later on the page, and includes the weighting value for each.

Two other documents in the package (changes suggested by Tierney and Freeze) add two more pressure values, for a total of 10, without documenting the rationale for the addition, or referencing any document which might explain it. These might be in the "source document" cited in the quotation above, but that quote specifies "...the 8 data points...", not "...8 of the data points...".

Further, the weighting assessments are different between the Tierney and Freeze two documents, and both differ from the weighting assessments in the original interpretation. No justification is given for changing these weighting factors.

The Freeze document is apparently one page from a larger document to which there is no reference tie. On the page included, the statement is made:

> The weights are approximately based on distance from the repository. Note that WIPP-12 (inside the site boundary) is assigned a weight of 0.45...The rationale for the weights for the highest pressures (17.4 and 20.0 Mpa [sic]) is described in a later paragraph.

No later paragraph in the included parts of the document describes weighting rationale for the added pressure values, and WIPP-12 is assigned a weighting value of 0.30, not 0.45, in the table just above the quoted statement (WIPP-12 is the 12.7 MPa pressure value).

The last page in the supporting documentation consists of two source document listings, one a SAND document and the other the 1992 PA. The references list specific page numbers; the referenced pages in both documents consist of descriptions of Salado porosity parameters, and would seem to having nothing to do with Castile brine reservoir pressure.

The Form 464 points to another SNL data package (WPO # 31072), which contains a memorandum listing the data that had been sent to the Natural Barriers Peer Review Panel (the Panel was to perform a necessary review for quality assurance purposes). However, there was no documentation of the findings of the Peer Review Panel in the package, or references to the Peer Review Panel Report.

Another parameter data package (Castile Brine Reservoir Permeability; WPO # 31070) which had been sent to the same Peer Review Panel did contain a memorandum that referenced the Panel Report qualifying the parameter.

Castile Reservoir Compressibility/Volume Documentation

Another parameter (Castile Brine Reservoir Rock Compressibility; Parameter # 61) offers an interesting set of memoranda from key SNL personnel. Briefly, in late August, 1996, a SNL scientist sent a memorandum to SNL's upper management in which he stated that

> ...I believe that treatment of brine reservoirs for the CCA was indefensible and non-conservative. I believe we are systematically underestimating the amount of brine that could reach the repository....The low end of the range comes from interpretation of hydraulic tests in Salado anhydrites, not from any direct Castile anhydrite measurements. The high end of the range comes from generic information reported by Freeze and Cherry (1979) for the compressibility of jointed or fractured rock, again not from actual Castile data...

The conclusion quoted above covers both the compressibility and volume of Castile brine reservoirs, which SNL analyses consider to be interdependent.

On October 3, 1996, the same scientist wrote another memorandum in which he concluded that, because the range of values he had calculated fell within the range used in the CCA, and other SNL personnel had told him that sensitivity calculations showed that the change in range would not shift the CCDFs, the treatment of Castile brine reservoirs in the CCA was acceptable.

However, whatever the effect on the CCDFs, the range used for the parameter in the CCA are still "...indefensible and non-conservative." None of the later memoranda contest this statement.

A graph of the data points appended to the October 3, 1996 memorandum shows that the new range lay in the upper end of the range used in the CCA calculations, and the data points that lay below the new range (38% of the total) were a much longer chain, while the ones above the new range (13% of the total) were more closely associated with the new range. Monte Carlo or Latin Hypercube Sampling would seem to result in more emphasis on lower values while using the CCA range than would be the case with the new range shown in the memorandum.

This package also received its QA acceptability from the Natural Barriers Peer Review Report (DOE/WIPP-96*2004). The peer review was held months before the new range was developed, and it would seem that a similar body should pass on the validity of the use of a new range of values for the parameter.

It may be worth noting that the discussion in the Natural Barriers Peer Review Report indicates that the peer review panel viewed Castile data from the WIPP-12 borehole in considering these parameters (see Report, p. 5-18) which the SNL scientist's memorandum stated was not used in the supporting documentation for the parameter.

Documentation of the Culebra Porosity Parameter As A Constant

The CCA (in Appendix PAR) states that:

> Parameters may also be assigned a constant value in the performance assessment parameter database. These parameters are tabulated at the end of the appendix. [PAR.2.1, end of section]

The Culebra porosity parameter (Parameter ID 140, Effective Porosity) is in the Table PAR-30 (Appendix PAR, p. PAR-214) as a constant value of 1.5100E-01. The Form 464 for the parameter (WPO #32769) describes the distribution type as a constant, and states a curious circular logic in the "Interpretation" section:

> The distribution equates a point and that point is equal to the mean. Therefore, that point is a constant.

However, the documentation appended to the Form 464 shows an approximate 30% standard deviation among the 103 data points used to establish the mean. Justification for the change (from a "student's t" distribution type) is a memorandum entitled "Distributions" (Tierney, March 21, 1996) that describes the use of the various types of distributions (cumulative, delta, normal, triangular, uniform, lognormal, loguniform) but does not a description for "constant" distributions. When SNL personnel were asked for documentation of the rationale for using a constant, a memorandum relating to category 3, physical constant parameters (Pi, Avogadro's number, etc) was the only information available (the porosity parameter is a category 1, derived from experimental data). In short, no justification is provided in the data package or seems to be available for considering this parameter to be a constant.

Documentation of Features, Events, and Processes (FEPs)

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 Compliance Certification Application (CCA). The documentation for the other 30% also appears to be incomplete. The rationale for excluding many of the FEPs from performance assessment (PA) is not documented in the CCA, as required by 40 CFR 194.32(e)(3).

The DOE originally developed a list of nearly 1200 FEPs, and the draft CCA (the DCCA; DOE/WIPP/CAO-2056, March 31, 1995) considered about 900 FEPs. For the CCA, approximately 240 were to be addressed, and about 90 of these are said to be "screened in", or used in the PA process. The DCCA list (≈900) is included as Appendix A to Attachment 1 of Appendix SCR to the CCA; the CCA list (≈240) are in the CCA as three tables, found in Chapter 6 (Tables 6-3, 6-4, and 6-5) and also in Appendix SCR (Tables SCR-1, SCR-2, and SCR-3).

No screening analysis plans were utilized for the reduction of the nearly 1200 FEPs to the approximately 900 included in the CCA, nor is there any documentation of the process used for each FEP. Reduction of the ≈900 was also performed without an analysis plan; this operation was later reviewed, and about 30% of the FEPs were passed on to the "SNL Side Efforts Program". The preliminary decisions on the other 70% of the FEPs seems to have been accepted without documentation of the process for including or excluding them. (The 70%-30% split of FEPs is taken from SNL documents and has not been independently verified by the EEG.)

The 30% that passed to the SNL "Side Efforts" program are required to have packages supporting the screening decision in the Sandia-WIPP Central Files (SWCF); these were to be screened based on the "FEPs Screening Analysis Plan, Version 5.2, for Phase I FEPs", dated 12-20-95 (for FEPs related to numerical and conceptual models), and "FEPs Screening Analysis Plan, Version 5-4, for Phase II FEPs" dated April 29, 1996 (for parameterized FEPs). However, at least 31 of the "Side Efforts" FEPs were only to be documented in the CCA (letter from DOE's McFadden to EEG's Neill dated August 2, 1996).

These 31 FEPs may have been part of a perhaps larger group of Phase II FEPs which were not processed in accordance with the analysis plan due to "resource constraints". The Change

Control Board was utilized to justify incorporating these FEPs into the CCA (see Wilmot, R.D., "Relationship of Side Efforts to the Compliance Certification Application" Galson Sciences Ltd 9507a-6, November 26, 1996, p. 2).

Not all of the 31 FEPs are documented in the CCA. Only "Side Efforts" FEPs were given an alphanumeric designator; the first FEP on the list (from the Neill-to-Dials letter dated July 11, 1996), "DR11, waste degradation", does not appear in the CCA nor did a rationale for its exclusion seem to be included. The Galson Sciences Ltd document cited above was written to document the location within the CCA of side efforts (p. 1); it indicates (Table 2, p. 15) that this FEP is

> ...not included in PA calculations [because]...Changes in mechanical and hydrological properties of the waste caused by corrosion need not be explicitly modeled.

Table 2 also indicates that the FEP is discussed within the CCA in Sections 6.4.3.1, 6.4.3.2, and 9.3.2.2.5. These sections do not provide a rationale for excluding waste degradation--indeed, the discussions in these sections only discuss waste in terms of consolidation (p. 6-97 & 6-98), gas generation (p. 6-100) and compaction (p. 9-138). The sections from Chapter 6 could be better used to show that consideration of waste degradation was included in the PA.

Appendix A, "DCCA Fep List By Category", of Attachment 1 of Appendix SCR to the CCA does list a general category of "1.9 Waste: degradation/corrosion/dissolution" with 12 subcategories (p. 26), but no alphanumeric designators are supplied. This seems to be the closest representation of the "Side Efforts" FEP designated as "DR11, Waste Degradation", in the CCA.

This illustrates a principal concern EEG has about the FEPs documentation process: many FEPs seem to be neither adequately defined nor consistently identified. FEPs would seem to require more than a two or three word designator to adequately delineate what is encompassed and excluded from the concept, but the CCA does not contain such descriptions, nor do such accurate definitions seem to exist.

A second concern is that 40 CFR 194.32(e) requirements for documentation seem to be inadequately met. 40 CFR 194.32(e) requires that the CCA include (1) identification of all FEPs that might affect the disposal system in the regulatory time frame; (2) a list of those used in PA; and (3) documentation of the rationale for excluding those not used. There are abundant lists that show which FEPs were used in PA (Tables 6-3, 6-4, and 6-5 of Chapter 6, which are duplicated in Tables SCR-1, SCR-2, and SCR-3 in Appendix SCR; and Table 4 of Attachment 1 to Appendix SCR), but the original list of ≈1200 FEPs has not been included, and the rationale for not including at least some of the FEPs seems to be missing.

A third concern is that the Change Control Board decision to incorporate FEPs which had not been processed in accordance with analysis plans would seem to have circumvented the WIPP quality assurance programs.

This leads to a fourth concern: it appears that much of the work on FEPs has not been performed in accordance with the Nuclear Quality Assurance (NQA) standards required by 40 CFR 194.22(a). NQA-1 Basic Requirement 5 states:

> Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances. These documents shall include or reference appropriate quantitative or qualitative acceptance criteria for determining that prescribed activities have been satisfactorily accomplished.

Prescribing instructions or procedures which included acceptance criteria were apparently not developed for much of the FEPs process.

When questioned about QA assessments of the FEPs screening and documentation process, SNL cited CAO surveillance S-96-21 as having covered the 70% FEPs in its assessment of the DCCA. According to the surveillance report, this assessment was conducted by one auditor and a software QA specialist over a five-day period (February 5-9, 1996), and covered training and personnel qualification, procurement control, document reviews, records, and software. The only part of the report that could possibly be considered an assessments of FEPs is in the section concerning technical document reviews (p. 4), which covered not only the entire DCCA, but also the RCRA permit application, No Migration Variance Petition, and an Engineered Alternatives study. There is no documentation that any FEPs were reviewed during this surveillance. Thus, the reduction of FEPs from ≈1200 for the CCA's ≈240 has not been assessed by an independent organization.

FEPs in the "Side Efforts" program were said by SNL to have been assessed during CAO surveillances S-96-04 (December 1995), S-96-32 (April 1996), and CAO audit A-96-03 (June 1996). The program was still in progress during this time period, and the Change Control Board decision may not have been fashioned yet.

FEPs Screening Decision Adequacy

For the CCA, FEPs were eliminated (screened out) from consideration in PA by one of three criteria: regulatory (SO-R), for FEPs excluded by language in 40 CFR 191 or §194; low consequence (SO-C) FEPs; and low probability (SO-P) FEPs, which are defined in §194.32(d) as processes and events with less than one chance in 10,000 of occurring over 10,000 years. For SO-P, the CCA offers a less stringent interpretation (Section 6.2.2.1 lines 20-23, p. 6-39):

> In practice, for most FEPs screened out on the basis of low probability of occurrence, it has not been possible to estimate a meaningful quantitative probability. In the absence of quantitative probability estimates, a qualitative

argument has been provided.

Some FEPs screening arguments seem inadequately supported. For example, GG-13, electrochemical gradients, is screened out on the basis of probability (Galson Sciences Ltd 9507a-6, p. 25). The argument offered in Appendix SCR (p. SCR-62) is:

> Galvanic coupling could lead to the establishment of potential gradients between metals in the waste form, canisters, and other metals external to the waste form. Such electrochemical effects can potentially influence corrosion processes and therefore gas generation rates and chemical migration...Good physical and electrical contact between the metals involved is critical to the establishment of galvanic cells. Experience with experimental investigations suggests that this requirement is unlikely to be achieved under repository conditions.

None of the experimental investigations are listed in Appendix SCR. However, the Sandia-WIPP Records Center does store supporting documentation for the CCA, and for this FEP the records package is WPO # 31491, "Electrochemical Gradients Qualitative Screening Arguments for Side Effort GG-13". This document echoes Appendix SCR, stating that the FEP is SO-P because:

> Good physical and electrical contact between the metals involved is critical to the establishment of galvanic cells. Experimental investigations suggest that this requirement is unlikely to be achieved under repository conditions (Telander and Westerman, 1993).

The cited document is SAND92-7347, "Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through December 1992". The EEG was unable to locate any descriptions of experiments or any data relating to physical or electrical contact between metals, or any references to galvanic cells or coupling in the document. The report covers experimentation on corrosion and consequent H_2 gas generation by low-carbon steel and alternative packaging materials in contact with gases (N_2, CO_2, H_2S) and brine, but offers no indication that interactions between metals was ever a consideration.

For this SO-P FEP there is not only no evidence that the 1 chance in 10,000 over the next 10,000 years criteria is met, there also appears to be no evidence for the less stringent qualitative argument offered.

In discussing this FEP, the DOE has intermingled electrochemical gradients (GG13) with another FEP, galvanic coupling (GG12), and then used an argument based on galvanic coupling to cover electrochemical gradients; this intermingling amounting to a circular argument exemplifies the EEG's concern about inadequate delineation of FEPs. Electrochemical gradients may be formed by means other than galvanic coupling (oxidizing conditions in one part of the repository, reducing in another, with brine linking them), and the possibility of such gradients should also be addressed.

Given the uncontrolled and intense compression the waste in the repository will undergo, it seems possible that the necessary physical and electrical contact between metals cited in the CCA as necessary for galvanic coupling can occur. The DOE's contention that this will not occur is unsupported by cited documents. A reliable and objectively supported argument should be advanced before rejecting the possibility--for both the GG12 and the GG13 FEPs.

FEPs Excluded on the Basis of Administrative Control

Table C-3 in Appendix C to Attachment 1 of Appendix SCR to the CCA (SCR p. 92 & 93) is titled "FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues relating to designs different to that forming the basis of the CCA".

The FEPs in the table are the sorts of events that would seem to require a more serious consideration before excluding them from PA. Among these are the FEPs "Backfill/seal material deficiencies", "inadvertent inclusion of undesirable materials", "poor quality construction", "radioactive waste disposal error", "stray materials left", "Preclosure events", "Faulty seal emplacement", "Inadequate seal or compaction, voidage", and "Seal material deficiencies", all of which would seem to be possible events which could alter the adequacy of the repository for its intended task.

"Abandonment of unsealed repository", another on the list, would certainly seem important enough to require close consideration. Will there be funding and a willingness to continue the WIPP for a full 35 years anticipated by the design presented in the CCA?
A statement in the narrative portion of Appendix C (pp. 11-12) addresses exclusion of these FEPs:

> FEPs relating to constructional, operational and decommissioning errors (classified as RD in the DCCA) have been eliminated from the CCA FEP list. The DOE has administrative and quality control procedures to ensure that the facility will be constructed, operated, and decommissioned as specified in the CCA.

The EEG considers this statement to be inadequate justification for excluding these FEPs. Among other examples, recent administrative and quality controls concerning drilling rights and privileges in the vicinity of WIPP (see recent EEG discussions of active and passive institutional controls) illustrate that such controls are not always effective.

Attachment 1
P. 1

General Considerations: DQC's

1. For sampled distributions, CCA Chapter 5 provides a good description of why simulation values need not be covered by DQC's:

   - Applicable to tasks involving quantification through sampling and analysis of specific constituents in an environmental medium (e.g., pollutants in wast streams   waste characterization and environmental monitoring).
   - The performance assessment is estimated using mathematical models rather than being determined by direct measurement.

     1) Parameters are treated as being uncertain variables, rather than precisely determined quantities and are characterized by probability distributions.

     2) Parameter distributions may span several orders of magnitude due to uncertainty introduced in susequent processing. Many parameters derived from data measurements need be known only within orders of magnitude of their true value. Efforts to reduce the range do not necessarily improve model accuracy.

     3) As an example, data accuracy would be very difficult to assess for geologic site characterization activities because reference or true values do not exist.

     4) In summary, it's not practicable to apply DQC's to most scientific investigations used support a performance assessment, in which there uncertainty in the conceptual models and the resultant ranges of parameters. Instead, controls established by the QA program provide the necessary quality.

2. There are a lot of technical discussions that could be presented to describe why DQC's don't apply to specific data sets The intent here is to provide some general discussion regarding the topic.

3. 194.22(c) itself says "...to the extent practicable, information which describes how all data used to support the compliance application have been assessed for their quality characteristics, including:...[PARCC]".

4. Natural features do not lend themselves to DQC's.

January 16, 1997

CATEGORY	DATA SET	DATA SET DESCRIPTORS	PRECISION, ACCURACY, REPRESENTATIVENESS, COMPLETENESS, COMPARABILITY (PARCC)
Dominant force - relative to releases	Particle Size	• Particle sizes of waste and backfill at the time of human intrusion • What future waste might look like 10,000 years • No physical data collected • interpretative • Sampled distribution	P. No physical data collected by project. Values were selected by smallest size analog materials & largest annular space. Smallest sized values determined from textbooks standard equations. A: No physical data collected by project. Values were selected by smallest size analog materials & largest annular space. Smallest sized values determined from textbooks standard equations. R: The uniform distribution assures that all possible values are fully represented. C: Distribution captures plausible and realistic values. C. N/A. Because there is only one data set. All of the available data were used.
Less important - relative to releases	The Probability of Microbial Degradation	• Interpretative • ~~Some data collected~~ • Estimate of the likelihood of occurrence of gas generation - 50% likelihood	P: Data collected was not used to determine the distribution. Model decision formulated - 50% likelihood (yes/no), if the process will take place. The 50% value reflects a lack of knowledge of the distribution. A: Data collected was not used to determine the distribution. R: 50%, only 2 possibilities. C: Based on ~~some experimental data and~~ interpretation. C: N/A: ~~Because there is only one data set.~~ For the 50% there are only 2 possibilities.
No Impact - relative to releases	Anhydrite Permeability	• A measure of a porous medium to transmit fluid • Experimental data • Field data • Laboratory data • Sampled distributions	P: A wide range of values doesn't affect release. The laboratory and field data were combined into a single data set. A: Distribution was set up to account for a wide range of data and uncertainty in data points. R: Latin Hyper Cube sampling assures that distribution and values fully represented. C: Latin Hyper Cube sampling assures that distribution and values fully represented. C: N/A: Because all of the available data were used to create the distribution.

Attachment 1, p. 2

CATEGORY	DATA SET	DATA SET DESCRIPTORS	PRECISION, ACCURACY, REPRESENTATIVENESS, COMPLETENESS, COMPARABILITY (PARCC)
Less important - relative to releases	Gas Generation Rates	• Rate of gas generation • Experimental data • Laboratory data • Sampled distributions	P: Variability in values doesn't significantly affect release. Wide variability due to a large range of conditions in ~~field~~/lab data dominates the variability in the individual experiments. Variability scatter of the data collection values is small compared with the much broader spread assumed by the distribution to account for uncertainties in the conditions. A: Variability in values doesn't significantly affect release. Wide variability due to a large range of conditions in ~~field~~/lab data dominates the variability in the individual experiments. Variability scatter of the data collection values is small compared with the much broader spread assumed by the distribution to account for uncertainties in the conditions. R: The Test Plan is designed to explore the range of conditions expected in the repository. The sampling assures that distribution and values are fully represented. C: Latin Hyper Cube sampling assures that distribution and values fully represented. C: N/A: Because there is only one data set.
Less important - relative to releases	Panel Closure	• Bounding argument • No data collected for panel closure	Permeability is larger than what we think the true value would be. Very conservative value. The true distribution of values would all lie below the assumed values and is therefore very conservative. R: Bounds all plausible values.
No Impact - relative to releases	Releases through the Culebra: Kd's	• Experimental data • Field data • Laboratory data • All distributions	P: Variability in values doesn't significantly affect release. Wide variability due to a large range of conditions in field/lab data dominates the variability in the individual experiments. Variability scatter of the data collection values is small compared with the much broader spread assumed by the distribution to account for uncertainties in the conditions. A: Distributions set-up for variability uncertainty. R: Representativeness of collection cannot be known for 100% certainty for natural features. Therefore accounted for by probabilistic method. C: Same as for Representativeness. C: N/A: Because all of the available data were used to create the distribution.

Attachment 1
P. 3

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003
FAX (505) 828-1062

December 31, 1997

Mr. Frank Marcinowski
Radiation Protection Division
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
401 M Street SW
Washington, DC 20460

Dear Mr. Marcinowski:

At our meeting on December 10, 1997 in Albuquerque, the EPA WIPP project staff asked us to provide a written description of each of the issues related to the EPA's draft rule on WIPP, that we presented that day. This letter is to provide you a summary of each of the issues that we presented, as well as summaries of the issues that we did not have the time to present that day. Where more details are needed, we have enclosed extended descriptions. As requested by your staff, we have made specific suggestions on how to resolve each of these issues. This letter is not a replacement for the material presented to the EPA, but supplements and amplifies it. Also, please note that our presentations at the 12/10/97 meeting, and this letter, constitute our initial reaction to the EPA's draft rule published on 10/30/97. As we continue to review the voluminous materials released with the draft rule, we will provide additional comments to you in the near future.

As we noted on December 10, the issues presented to the EPA were those for which we have additional analyses or arguments. The issues not discussed that day were those for which we have previously provided detailed comments to the EPA, but the EPA has disagreed with our position, as indicated in the Draft Rule. Those issues are also included here with our reasons for continuing to believe in our previously stated positions. We trust that this material will be of use to you in your continuing review of the DOE application.

SUMMARIES OF THE ISSUES PRESENTED ON 12/10/97

Solubility

In reviewing the basis for the selection of actinide solubilities in the CCA and PAVT calculations, the EEG finds that the FMT model is unique to WIPP and is not 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 (Oct. 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" (EPA, III-B-17, p.35). 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. The problem with this assumption is that the plutonium and citrate are 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 (Van Bynum's 4/23/97 report); a hydromagnesite-like unnamed mineral is reported. The chemical structure 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." (EPA Technical Support Document III-B-17, p.2). 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 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.

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. The investigation (Enclosure 1) 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 (Enclosure 1, Fig.1).

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 3/14/97 Neill to

Marcinowski letter. The DOE submitted a response as an attachment to the 6/27/1997 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. 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 recommends 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.

Review of the EPA Spallings Investigation
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 (TSD III-B-10 and TSD III-B-11). 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 cannot 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. It should be on the immediate transport of material from the formation of an explosive spall cavity, as in the most recent DOE model.

The EPA modeling is superceded by the new spallings model presented in January 1997 (Hansen et al., 1997) to the DOE's Conceptual Model Peer Review Panel. The Panel rejected the CCA model and accepted this new model. This new model predicts that almost all spall would come from the face of the drilling cavity and that 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.* predicts that spalling will stop after a few seconds and that depressurization is negligible beyond roughly 1.5 meters at this time. 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 hundred 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.* 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.* model. These differences in both temporal and spatial discretization are an indication that the EPA modeling cannot predict gas velocities from local depressurization reliably. Hence, the EPA model cannot be used to judge the conservatism of the spall model described *by Hansen et al.,* nor the extension of the *Hansen et al.* model to potential spall from air drilling.

Hansen et al. also considered the issue of maximum particle size that could be transported up the borehole. Their results indicate 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 discretization of the EPA model is too coarse to accurately calculate the flow rates this early in the 11-day period. In conclusion, the calculations of *Hansen et al.* indicate that transport of spall material up the borehole will not limit the release of spall material to the surface.

The EEG therefore recommends to the EPA to **not** use the results of simplified modeling contained in the draft rule attachments TSD III-B-10 and III-B-11 to confirm the validity of the CCA spallings model, or to limit the potential releases from air drilling.

Stuck Pipe/Gas Erosion Scenarios
"Stuck pipe" is a scenario that occurs when, due to very low permeability of the waste and extremely high pressures in the repository, the amount of failed waste (spall) is more than the carrying capacity of the drilling mud. The spall then presses against the drill string sufficiently hard to slow down the rotation of the drill bit, preventing normal drilling. To free the jammed bit, the drillers 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. "Gas erosion" refers to the scenario in which the failed waste is slowly eroded by the drilling mud when the repository pressure is just above hydrostatic and the waste permeability is low. Under these conditions, waste may be released 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 bring significant quantities of waste to the surface in the process. Both these scenarios were considered by the DOE in an earlier exercise in the WIPP performance assessment (Systems Prioritization Method, 1995), but were not considered in the CCA because the permeability of the waste was assumed to be higher than the threshold for these processes to occur.

The CCA (Chapter 6, p. 6-100) states that permeability of the waste compacted under a lithostatic load was found to be in the range of 10^{-12} to 10^{-16} m^2, but assigns a constant value of $1.7x10^{-13}$ m^2, which is much greater than the assumed threshold of 10^{-16} m^2 for the "stuck pipe" scenario.

This issue was first raised in my February 7, 1997 letter to you, and has been numbered 540 in the draft rule (CARD 23). The response to Comment 540 states that the phenomena of stuck pipe will not occur because the permeability of the waste in the CCA (DOE, 1996-Chapter 6) was greater than the threshold permeability for stuck pipe stated in the CCA (DOE, 1996-Appendix CUTTINGS_S). The EPA quotes additional studies of permeability made by the DOE, in which the waste permeability was found to be 100 times less than the CCA value (Hansen et al., 1997), but still greater than the threshold permeability. Thus, the EPA does not believe that stuck pipe and gas erosion are processes to be considered in the CCA spallings model.

The EEG continues to believe that the "stuck pipe" is a plausible scenario because the threshold of $1x10^{-16}$ m^2 for stuck pipe and gas erosion may be faulty. This value resulted from the CCA Spallings model (as part of CUTTINGS_S), which was found to be conceptually flawed.

Berglund (1994) states that, for model simplicity, a value of $1x10^{-16}$ m^2 will be used for a cutoff for blowout. The new spallings model, GASOUT (Hansen et al., 1997), shows that blowout will cease when permeability is between 10^{-14} and 10^{-15} m^2. Berglund (1994) has shown that when blowout stops, the stuck pipe and gas erosion mechanisms of spall take over because the failed waste will be introduced into the borehole cavity and will not be blown out. Thus, the permeability threshold for the stuck pipe and the gas erosion scenarios appears to be 10^{-14} to 10^{-15}, rather than 10^{-16}. In any case, because of the stuck pipe and the gas erosion scenarios coming into play when the blowout ceases, release to the surface will occur even when the conditions for blowout of the mud column cease. We therefore recommend that it should be assumed that all of the calculated spall material will reach the surface.

Furthermore, the permeability of the waste in the WIPP repository is quite likely to be lower than that anticipated by the DOE. None of the waste surrogates for permeability testing included MgO as a backfill material. It is suspected that MgO precipitation will decrease the permeability by providing material for interstitial cementation, which has been postulated by the DOE's Particle Size Expert Elicitation Panel to be a major contributor to increased waste strength and lower permeability. Since the permeability of the waste is such a key parameter in assessing compliance with the standards, additional permeability measurements on surrogate waste that includes magnesium chloride cement should be carried out. Until this is done, the calculations may sample on the 10^{-12} to 10^{-16} range.

To get a perspective on the potential magnitude of impact of these scenarios on compliance, the EEG conducted calculations to investigate the amount of spallings release through either the stuck pipe or the gas erosion process that would violate the EPA standard. Enclosure 3 shows that if between 8 m^3 and 64 m^3 of spalled material is assumed to reach the surface, the standard is violated at 10^{-1} probability. The EEG is in the process of computing the releases from the stuck pipe and the gas erosion scenarios, and will transmit the results to the EPA as soon as possible.

Brine Release in Air Drilling

The EEG has investigated the effect of air drilling on direct brine release, and the results are shown in Enclosure 4. The results show that brine releases to the surface could be between 1000 and 2000 m^3, compared to a maximum of 180 m^3 from the EPA's PAVT computations. The CCDF from the EEG's runs show that the overall mean for all types of releases (including brine release from air drilling) comes very close to the EPA limit at 10^{-3} probability for the actinide solubilities assumed in the CCA, and violates the standard at the "no backfill" and "nesquehonite" solubilities.

Fluid Injection Scenario

The petroleum reservoirs surrounding and underlying the WIPP are potential candidates for fluid injection to recover a substantial amount of crude oil reserves. 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. In fact, concerns about unexplained water losses due to solution mining, potential oil field development, or future oil field waterflooding has helped eliminate other sites from consideration as documented in an EEG report on fluid injection (Silva 1996; EEG-62). The EPA proposes to accept the DOE position that fluid injection can be ruled out as a potential scenario and, hence, need not be considered in the performance assessment calculations.

For fluid injection activities on leases adjacent to the site, the DOE argues that such events can be eliminated from further consideration on the basis of low consequence. The EPA 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"(CARD 32, p.42). The DOE chose to examine consequence rather than probability, as noted by Stoelzel and O'Brien, "[because 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 Obrien 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 (EPA, III-B-22, Table Q). But this value appears to be based on an optimistic view of future injection well performance and does not reflect the actual experience of documented waterflows in the Salado Formation in water flood areas throughout southeast New Mexico.

In the final analysis, for the low consequence argument, the EPA has accepted the modeling results of Stoelzel and O'Brien (1996) and Stoelzel and Swift (1997) for DOE, and has rejected the modeling results of Bredehoeft (1997) for the New Mexico Attorney General. The DOE maintains that a leaking injection well in the vicinity of WIPP is a low consequence event. But a very fundamental question remains. Can the DOE 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? Can these codes model the migration of substantial amounts of water through a single zone of the Salado Formation, two miles in the up dip direction, in about 12 years? That has yet to be shown. Unless the code is verified with actual field data, the low consequence conclusion will remain a speculation at best.

The EPA does not anticipate that CO_2 injection for oil recovery will be a widespread practice in the future near WIPP (EPA CARD-23, p. 131). However, EPA's reasons do not have supporting references and appear to be at odds with the published literature. The EPA technical support document (III-B-22) 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; Trash 1979)". But an examination of the current and relevant literature strongly suggests that the Delaware Mountain Group sands are excellent prospects for future CO_2 flooding. 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. Third, oil and gas companies continue to purchase mature fields, such as the El Mar in the Delaware Basin, specifically for carbon dioxide flooding. Fourth, the recently drilled reservoirs surrounding the WIPP such as Cabin Lake, Livingston Ridge, Los Medanos, and Lost Tank have oil and reservoir characteristics that easily qualify them as potential candidates for future CO_2 flooding using the enhanced oil recovery (EOR) screening criteria.

EPA maintains that "there are no natural gas storage horizons in the Salado Formation" (EPA CARD-32, p.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", according to entry in a State document.

There are other fluid injection issues that have either not been fully addressed or in which there appears to be a misunderstanding of the issue including, for example, the yet to be explained water level rises in the Culebra Aquifer, the likely expansion of solution brine wells in the Delaware Basin, and the likely initiation of solution mining activities in maturing potash mines.

SUMMARIES OF THE ISSUES NOT PRESENTED ON 12/10/97

The following are the summaries of the other important issues related to the CCA and the Draft Rule that were not presented to your staff on December 10, but have been previously presented to the EPA.

Waste Issues

EEG has concerns about some EPA conclusions regarding: (1) waste inventory and waste form; (2) waste characterization; and (3) waste repository limits.

Waste Inventory and Waste Form:
The EPA has concurred with the DOE's contention that there is no uncertainty in the waste inventory. EEG's view is that: (1) there is considerable uncertainty in the stored inventory; (2) there is uncertainty in the volume of newly generated waste and the processes at the generating sites have changed significantly since the stored waste was generated; and (3) DOE plans to treat most of the waste at INEEL and the RFETS (residues) and repackage, and treat for size reduction, at other facilities. These plans are not reflected in the CCA inventory.

EPA should recognize this uncertainty and either not accept the DOE inventory and Waste Material Parameter (WMP) values or not permit DOE to bring in waste that differ significantly from the values in the CCA until more accurate inventory data have been developed and used in the PA calculations.

Waste Characterization:
DOE has concluded that a maximum repository limit of $2x10^7$ kg of cellulosics, rubber, and plastic (CRP) should be set 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 $2.1x10^7$ kg (see CARD 24-38).

EEG is concerned about the ability to measure CRP in the waste with enough accuracy to ensure that this 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, 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 at this time.

Waste Repository Limits:
DOE has concluded that all repository limits need to be controlled only for the full repository. EPA has concurred in this recommendation and concluded that DOE's WIPP Waste Information System (WWIS) is capable of controlling repository limits.

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 the case for controlling limits on a repository basis has not been justified. We recommend control on a per panel basis, at least, until the inventory is known with more certainty.

Retardation Coefficient
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 (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.

The EEG recommends that the EPA consider the EEG submissions to the docket before reaching a final conclusion on the issue.

Brine Reservoir Probability
The EEG raised a number of issues related to the Castile Formation brine reservoirs (see R.H. Neill letters to F. Marcinowski, dated 2/7/1997 and 3/14/1997, attachments "Brine Reservoir Assumptions"). 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.

Assurance Requirement/Engineered Barriers
The EEG believes that in allowing the resource disincentive requirement of the EPA standards (40 CFR 191.14 e) 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 "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 (EEG-61, May 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 (in EEG-61) 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 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 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 directive 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 (DOE/ES-0026-S-2), 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, DOE/NTP.-96-1204, Rev.1.

- 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 the plutonium residues and 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.

We look forward to continuing the dialogue with you to resolve these and other issues.

Sincerely,

Robert H. Neill
Director

RHN:js
Enclosures

cc: Mr. Richard Wilson, EPA
Mr. Larry Weinstock, EPA
Ms. Mary Kruger, EPA
Mr. Chuck Byrum, EPA
Mr. Tom Peake, EPA
Mr. George Dials, DOE
Mr. Chris Wentz, NMEMNRD
Mr. Lindsay Lovejoy, Jr., NMAG
EPA Docket for WIPP (A-93-02)

(Enclosure 1 to the 12/31/97 Letter From R.H. Neill, EEG to F. Marcinowski, EPA)

Issue: Solubility Modeling

The modeling of solubility changes to the PAVT started with the re-running of the ‘Source Term’ files. The Latin Hypercube Sampling (LHS) generated a range of solubilities in the CCA that were 2.0 and 1.4 orders of magnitude below and above the median values, respectively. For the present model the range of solubilities were reduced to a constant value, based on solubilities of ‘No Backfill’ from Van Bynum (1997), and Nesquehonite in Novak (1997). The parameters of SOLSIM (solubility factor for Salado) and SOLCIM (solublity factor for Castile) (DOE, 1996-Appendix PAR) were changed for the oxidation states of +3, +4, and +6.

Table 1 shows the values used to replace SOLSIM and SOLCIM for all the actinides for the different mineral types. Again, the range from -2.0 to 1.4 with a cumulative continuous distribution was changed to the values below with a cumulative discrete distribution. One hundred vectors were created for all six scenarios of the first replicate with the new LHS file.

Once Source Term files were created, PANEL was rerun with the new solubilities using BRAGFLO files of the PAVT. The BRAGFLO files supply the velocity information for PANEL to use in the transport equations. The PANEL ‘concentration’ simulations were ran for 100 vectors of S1 and S2 scenarios. The PANEL ‘time’ simulations were reran for 100 vectors of S6 for times 100, 350, 1000, 4000, 6000 and 9000 years postclosure.

Lastly, the PANEL files were incorporated into the CCDFGF to create CCDF curves for comparison with 40 CFR Part 194. In addition to the Nesquehonite and No Backfill simulations with PANEL to create the new CCDFs, the CCA PANEL files containing CCA solubilities were used with PAVT releases of direct brine release, cuttings, spallings, and transport through the Culebra. Figure 1 shows the CCDF results of the different solubilities.

The figure shows that none of the curves violate the standard. The CCA solubility model has an estimated release of 0.45 EPA units at the 10^{-3} probability level. This is slightly higher than the 0.37 EPA units of the PAVT model and 0.22 EPA units of the CCA. The releases are shown to increase to 6 EPA units for Nesquehonite solubilities and to 7.5 EPA units for ‘No Backfill’ solubilities. The EPA compliance limit for the 10^{-3} probability level is 10 EPA units, or 3500 Ci for Plutonium, Uranium, Thorium, and Americium.

References

Bynum, R.V., 1997. Chemical Conditions Model: Results of the MgO Backfill Efficacy Investigation, SAND97-2511. Albuquerque, NM: Sandia National Laboratories.

Novak, C.F., 1997. Memorandum from Craig F. Novak to R. Vann Bynum “Calculation of Actinide Solubilities in WIPP SPC and ERDA6 Brines Under MgO Backfill Scenarios Containing Nesquehonite or Hydromagnesite as the $MgO\text{-}CO_3$ Solubility-limiting Phase”. Albuquerque, NM: Sandia National Laboratories. WPO# 46124.

U.S. Department of Energy, 1996. Title 40 CFR 191 Compliance Certification Application. DOE/CAO-1996-2184.

	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

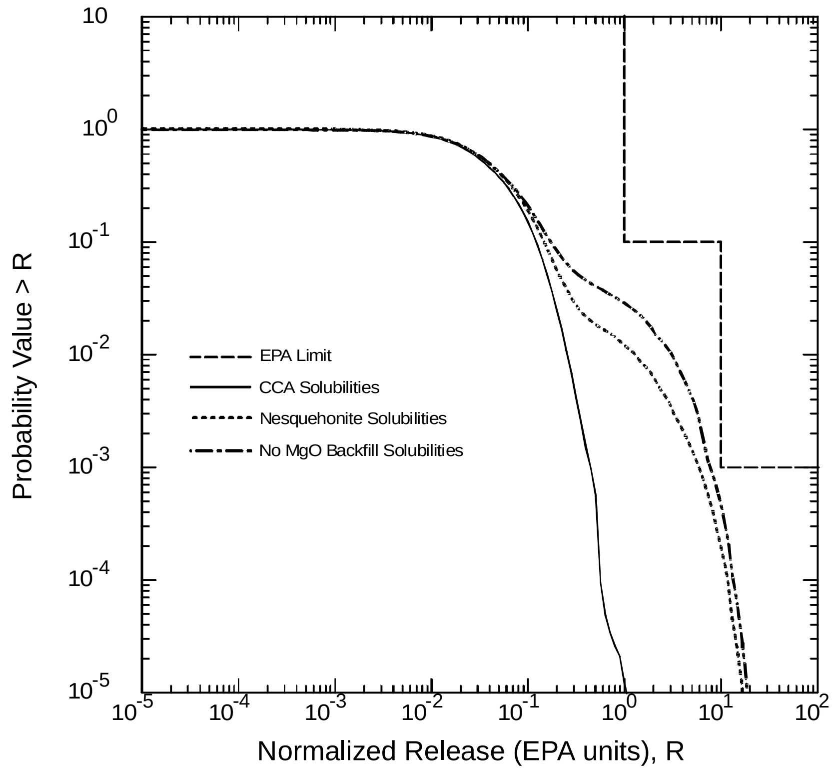


Figure 1. CCDF Overall Mean for Solubility Modeling with the CCA, Nesquehonite, and 'No Backfill' Values.

(Enclosure 2 to the 12/31/97 Letter From R.H. Neill, EEG to F. Marcinowski, EPA)

Issue: Three Dimensional Processes and Boundary Conditions

Problem Description

The EEG first brought this issue to the EPA's attention as an attachment titled ABrine Inflow From Salado: 2-D versus 3-D Geometry in BRAGFLO to the 3/14/97 letter from R.H. Neill to F. Marcinowski. The DOE submitted a response as an attachment to the 6/27/1997 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 as Comment #553 on page 115 of CARD #23, and the EPA response is provided on page 116. This issue was presented by the EEG to the EPA on December 10, 1997 as 2D/3D Modeling in BRAGFLO.

The FEP Screening Analysis titled S1: Verification of 2D-Radial Flaring Using 3D Geometry (*Vaughn et al.*, 1996) compared the two dimensional radial flaring model of BRAGFLO used in the CCA performance assessment to a three dimensional BRAGFLO model of the repository. The 3-D model calculated a large flow of brine into the repository after the pressure reached the anhydrite fracturing pressure. The large flow did not occur in the 2-D model. Figure 1 shows the pressure history for the two models. The scenario used for the investigation included a drilling intrusion at 1,000 years, accounting for the large drop in pressure at that time. Our concern is the difference in behavior of the two models after the pressures reach 12.7 MPa but prior to 1,000 years.

Figure 2 depicts the calculated brine inflow and outflow rates. The figure shows a large difference in calculated inflows of the two models during the period of 700 to 1,000 years. Figure 3 reinforces the perception that the brine inflow in the 3-D model is large. As shown in Figure 3, during the 700 to 1,000 years period the 3-D model shows a decrease in gas saturation of 0.05. Our concern is that if the brine inflow calculated in the 3-D model persists for thousands of years then the 2-D model calculations significantly under-predict repository saturation at high pressures.

Greater saturations could lead to much larger direct brine release calculations. Figure 4 (Figure 5.1.5 of *Helton)* is the basis of this contention. Figure 4 depicts the relationship of calculated direct brine releases to repository conditions at three separate times. The average repository brine saturation and repository pressure are plotted for each vector on the horizontal plane. A vertical line connects the plane to a small circle at the level of the vertical axis corresponding to the volume of brine calculated to reach the surface. Calculated releases greater than one cubic meter are highlighted using a filled circle.

Figure 4 indicates that there were few calculated direct brine releases when the calculated repository pressures exceeded 12.7 MPa and almost none when the pressure exceeded 14 MPa. Almost all of the larger calculated direct brine releases occurred when brine saturations were above 0.5, a condition never calculated at pressures above 14 MPa. The FEP S-1 analysis suggests that the potential for many of the vectors with great repository pressure to also have large brine saturations. Thus calculated direct brine releases might have both larger volumes and greater frequency in the performance assessment.

EEG Assessment of DOE Response to Comment # 553

The major concern of the EEG is that the 3-D modeling of the repository system indicates the potential for large brine inflow to the repository at high pressure which leads indirectly to the potential of larger direct brine releases than calculated in the CCA. The DOE has presented three independent lines of reasoning to indicate that the EEG's concern is unwarranted. If convinced that any of these lines of reasoning are correct then the EEG will concur with DOE's assessment that the issue is of little concern.

DOE's three arguments are: 1) Additional brine will be consumed by corrosion and the resultant gas generation will not cause greater repository pressures. 2) The difference in the two dimensional and three dimensional models only occurs at pressures above those calculated during the performance assessment for CCA. 3) The changes in the repository consistent with the three dimensional model are of little consequence to the performance assessment.

At this time, the first two of the lines of reasoning appear to be flawed. The third argument relies on the CCA values of actinide solubility that the EEG is not convinced are correct.

1. *Additional brine will be consumed by corrosion and the resultant gas generation will not cause greater repository pressures.*

That additional brine inflow will lead to more gas generation is not questioned. The flaw in this argument is that the potential brine inflow is too large to be consumed in a short period and could lead to large enough amounts of additional gas to significantly effect the pressure. The result could be both larger brine saturations and higher pressures. Figure 1 indicates that lower pressures are also possible. In the FEP S-1 the rate of gas generation was assumed to be constant. Thus, there was no feedback between brine inflow and gas generation in the FEP S-1 study.

The DOE cites the amount of iron remaining in the repository (Figure 5; *DOE*, 1996 Figure 12-13) as support for the argument that more brine inflow will lead to more gas generation not higher saturations. Figure 6 (Figure 2.2.9 of *Helton*) shows less iron remaining in the lower (waste) panel, presumably due to relatively more brine inflow to the lower panel (Pg 2-18 of *Helton*, 1996). Figure 7 (Figure 2.2.7 of *Helton*, 1996) shows that at most 30,000 cubic meters of brine are predicted to be consumed through iron corrosion. In most vectors, the calculated brine consumption was less than 15,000 m^3. In many, brine consumption continues though-out the 10,000 year compliance period. Other vectors show a secession of brine consumption after less than 2,000 years, presumably due to exhaustion of available brine (See Section 2.2 of *Helton*). Figure 2 suggests that brine inflow from fracturing may be on the order of 10 m^3 / year or more and continue for hundreds to thousands of years. Drawn on the Figure 7 is a line with a slope of 10 m^3 / year. Comparing the brine consumption with this slope indicates that the potential brine flow is large compared to the rate of brine consumption. The potential brine inflow is greater than 10,000 m^3. Most of this flow would likely be into the lower panel. The maximum amount of brine consumed in the lower panel was 6,000 m^3 (Figure 8, Figure 7.2.1-10 of *Bean et al.*).

2. *The difference in the two dimensional and three dimensional models only occurs at pressures above those calculated during the performance assessment for CCA.*

DOE cites Figure 9 (Figure 2.3.2 of Helton), showing the 10, 50 and 90 percentile pressures for each replicate for the 10,000 years, as demonstration that pressures will not increase greatly above 12.7 MPa. In fact, Figure 10 (Figure 2.3.1 of Helton), which depicts the pressure history of each vector of replicate 1, indicates that many of the calculated pressures were greater than 13 MPa and that for one vector the calculated pressure reached close to 16 MPa. 16 MPa is less than 2 MPa below the 17.5 MPa peak pressure of the 2-D simulation of the FEP S-1 analysis (Figure 1). The DOE has offered no explanation of what happens between 16 and 17.5 MPa to cause such large brine inflow in the 3-D simulation but not the 2-D simulation. A believable explanation is that the change occurs at initiation of anhydrite fracturing not just above 16 MPa.

3. *The changes in the repository behavior consistent with the three dimensional model are of little consequence to the performance assessment*.

There are two obvious potential impacts on the performance assessment calculations from greater pressure and brine saturations in the repository. Greater pressures would lead to larger calculated releases from the spallings model. If the spallings model described in Hansen et al. is correct then it is unlikely that the volumes brought to the surface because of greater pressures would approach those calculated in the CCA.

Either greater pressures or saturations could lead to much larger direct brine release calculations. Figure 4 indicates that there were very few calculated direct brine releases when the calculated repository pressures exceeded 12.7 MPa and almost none when the pressure exceeded 14 MPa. Almost all of the larger calculated direct brine releases occurred when brine saturations were above 0.5, a condition never calculated at pressures above 14 MPa. The FEP S-1 analysis suggests that the potential for many of the vectors with great repository pressure to also have large brine saturations. Thus calculated direct brine releases might have both larger volumes and greater frequency in the performance assessment.

Direct brine release was a minor component of the total calculated radionuclide releases in the CCA (Figure11; Figure 6-41 of the CCA). The volumes of direct brine release would have to be two orders of magnitude greater to have an impact on agreement with the containment requirements which is large in relation to a possible increases in the calculated volumes of brine brought to the surface through direct brine release. However, the radionuclide content of brine brought to the surface may be underestimated in the CCA which would make direct brine release of greater significance to the performance assessment (See EEG comments on solubility).

EEG Response to EPA's Resolution of Comment # 553.

The EPA's resolution of this comment relies on the fact that Abrine and gas saturations are inversely related. This relationship does not necessarily lead to higher brine saturations indicating lower pressures or less gas in the repository. The statement AThe 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.@ is a conclusion that the 3-D modeling results may indicate is not valid.

Consider Figure 4. This figure provides a plot of calculated brine saturation and pressure conditions in the repository at three separate times for undisturbed performance. This figure shows a correlation of brine saturation with repository pressure. There are at least three mechanisms that may lead to such a correlation:

A) Faster corrosion rates lead to more gas generation, less brine and greater pressures. Table 1 (Table 2.3.1 of *Helton*) lists the parameters most closely correlated with pressure in the lower waste panel. The list results from a step wise rank regression of the sampled parameters with pressure. The parameter that correlates the most pressure is listed first. The table lists the microbial degradation of cellulose and rubber and plastics (WMICDFLG) as the most important factor with halite porosity (HALPOR) next. Table 1 indicates that sampled corrosion rate (WGRCOR) is not a dominant factor in repository pressure. Halite porosity is a reasonable surrogate for brine availability (see Figure 2.1.5 of *Helton*).

Table 2 (Table 2.2.2 of *Helton*) lists halite porosity as by far the most important controlling factor over iron consumption. The second most important factor is the corrosion rate. Other parameters identified as slightly correlated with repository pressure and fraction of steel remaining are: ANHPRM (unfractured anhydrite permeability), SALPRES (Far field pressure in the Salado Formation), SHRGSSAT (residual gas saturation in the shaft seal), and WASTWICK (the parameter describing the tendency of brine to be pulled above the lower part of a room by capillary forces)

Figure 12 (Figure 2.4.3 of *Helton*) provides important supporting evidence. The figure presents the fraction of iron remaining in the lower waste panel (FEREM_W) or in the rest of the repository (FEREM_R) with respect to halite porosity, microbial degradation, steel corrosion rate. The plots of remaining iron and halite porosity suggest that a sufficient supply of brine is needed for iron consumption but other factors also limit corrosion. The main factor is probably corrosion rate. Figure 12 shows that low corrosion rates limit iron consumption, but that predicted iron consumption is not strongly dependent on corrosion rate. The comparison of iron remaining to microbial degradation is important because its strong correlation with repository pressure (Table 1). These plots show that the fraction of iron remaining in the repository is only weakly correlated with microbial degradation and that the correlation is positive e.g. microbial degradation, hence pressure, is inversely correlated with iron consumption. This inverse correlation is probably linked to the availability of brine.

B) Less brine flows into the repository at high pressures, at least in the 2-D BRAGFLO model used for the CCA performance assessment.

C) The repository inflates as the pressure rises (Figure 13; Figure 2.3.5) leading to more void space and lower saturations per unit volume of brine. Figure 13 indicates that the calculated void space in the repository is twice as large at 12 MPa than at 5 MPa and nearly three times at 16 MPa. Thus, the correlation of brine volume to pressure is much weaker than the correlation of saturation to pressure seen in Figure 4.

The FEP S-1 screening analysis concluded that the increased brine inflow to the repository in the 3-D simulation did not increase release to the accessible environment through the marker beds. The EEG agrees with this conclusion. It has not been demonstrated, however, that the increased flow into the repository predicted using the 3-D geometry will not lead to much greater releases from human intrusion. The 3-D modeling indicates that there is a potential for the combination of high pressure and relatively high brine saturation in the repository at the same time. This combination did not occur in the performance assessment modeling for the CCA and thus conclusions of the impact on radionuclide releases due to human intrusion can not be assessed using the CCA performance assessment.

The DOE has not yet demonstrated that the performance assessment modeling for the CCA accurately represents the potential repository conditions. 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.

Recommendations for Resolving the Issue

To resolve this issue, the EEG recommends that a few 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.

REFERENCES

Bean, J.E., M.E. Lord, D.A. McArthur, R.J. MacKinnon, J.D. Miller, and J.E Schrieber, , 1996, Analysis Package for the Salado Flow Calculations (Task 1) of the Performance Assessment Analysis Supporting the Compliance Certification Application (WPO # 40514).

DOE, *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant*, DOE/CAO-1996-2184, December, 1996.

Helton, J., Memo: Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Sandia National Laboratories, December, 1996.

Vaughn, P., T. Hadgu, D. McArthur, and J. Schreiber, FEP Screening Analysis S1: Verification of 2-D Radial Flaring Using 3D Geometry, Memorandum to D.R. Anderson, January 26, 1996, WPO 30840, Sandia National Laboratory, Attachment 4-1 to Appendix Mass of the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, DOE/CAO-1996-2184, December, 1996.

Figures

Figure 1: Average Pressure in Repository, FEP S-1 Analysis
From Vaughn et al, 1996.

Figure 2: Cumulative Net Brine in and outflow at Repository, FEP S-1 Analysis
From Vaughn et al, 1996.

Figure 3: Average Gas Saturation in Repository, FEP S-1 Analysis
From Vaughn et al, 1996.

Figure 4: Three dimensional scatter plots for volume of brine reaching the surface due to direct brine release for a drilling intrusion into the lower panel.
From Helton, 1996.

Figure 5: Fraction of Initial Iron Remaining in Repository
From: DOE, 1996.

Figure 6: Remaining Fraction of Steel Inventory in Waste Panel
Modified from Figure 2.2.9 in Helton, 1996.

Figure 7: Cumulative Volume of Brine Consumed by Corrosion in the Repository
Modified from: Helton, 1996.

Figure 8: Cumulative Volume of Brine Consumed in the Waste Panel
From Bean et al., 1996

Figure 9: Percentile curves for three replicated LHSs for pressure in waste panel
From: Helton, 1996.

Figure 10: Pressure in waste panel
Modified from Figure 2.3.1 of Helton, 1996.

Figure 11: Mean CCDFs for Specific Release Modes, Replicate 1.
From DOE, 1996.

Figure 12: Scatter Plots of the Fraction of Iron Remaining in the Waste Panel (Right Frames) and Rest of the Repository (Left Frames) for Undisturbed Conditions at 10,000 Years.
From Helton, 1996.

Figure 13: Scatter plot of pressure versus total pore volume in the repository.
From Helton, 1996.

Tables

Table 1: Stepwise Regression Analysis with Rank-Transformed Data for Pressure in the Waste panel at 10000 years. From Helton, 1996.

Table 2: Stepwise Regression Analysis with Rank-Transformed Data for Fraction of Steel Remaining and Total Gas Generation in Upper and Lower Waste Panels at 10000 years.
From Helton, 1996.

FULL TEXT OF ORIGINAL EEG COMMENT

Environmental Evaluation Group Review of the WIPP-CCA, 3/14/97

BRINE INFLOW FROM SALADO: 2-D VERSUS 3-D GEOMETRY IN BRAGFLO

The 2-D geometry used in the BRAGFLO appears to have caused an under-prediction of brine inflow to the repository and thus may have resulted in a significant under-prediction of the direct brine release. This assumption may also have effected the amount of releases predicted by the spallings scenario.

The justification for modeling the repository in a pseudo 3-D manner (2-D radial flaring) rather than in a full 3-D geometry has been provided through evaluation of FEP S-1. The summary memo of record for the FEP S-1 screening analysis[1] discusses the impact of the 2-D assumption on 1) brine flow through the anhydrite layers to the 2.4 km boundary, 2) flow to the top of the shaft, 3) brine flow up the borehole, and 4) the repository pressure. This memo does not consider the effects of the 2-D assumption on the inflow of brine to the repository, and on the spallings or direct brine releases.

The amount of projected inflow of brine in the repository directly effects the gas pressure in the repository. Table 5.5.3 of the sensitivity analysis report[2] lists the residual gas saturation as the parameter with the strongest influence on the projected direct brine releases. This is also shown in Figure 5.1.5 of the sensitivity analysis report (the attached Figure 1). In addition, brine inflow is important to the spallings release estimates through increased gas generation. This dependence is made clear in Table 4.4.3 of the sensitivity analysis report which lists halite porosity, a large source of brine, as the second most important parameter to spallings releases.

The screening analysis compared 2-D simulations of the repository to 3-D simulations of the repository. For computational efficiency, the calculations were performed for half the repository. Two sets of simulations were conducted for the analysis. One set of calculations used a gas generation rate below the level that would cause anhydrite bed fracturing. The second used twice the gas generation rate to ensure anhydrite bed fracturing. In both sets, less brine-inflow occurred in the 2-D case compared to the 3-D geometry. No dependency of gas generation on brine inflow to the repository was included in the calculations; gas generation was prescribed as a function of time, ending after 1,000 years in the screening calculations.

The largest impact of 2-D geometry occurs with anhydrite bed fracturing. The 3-D model predicts the flow into the repository to significantly increase if the anhydrite beds fracture, while the 2-D model predicts the flow to decrease in relation to calculations without anhydrite fracturing.

Figure 15 of the FEP S-1 analysis (Figure 2) shows the cumulative brine inflow to the repository for the high gas generation calculations. The flows calculated using the 3-D model indicate that once anhydrite bed fracturing occurs roughly $2x10^6$ kg (1,600 m^3) of brine enters the repository in a period of 200 to 300 years and that this flow rate was continuing unabated at the time of drilling intrusion. Another $4x10^6$ kg (3,200 m^3) flowed into the repository shortly after the drilling intrusion. Figure 2 shows differences of $4x10^6$ to $6x10^6$ kg (3,200 to 6,500 m^3) for much of the 10,000 years. The brine inflow differences listed above should be doubled for the full repository. Virtually no flow enters the repository as a result of anhydrite bed fracturing in the 2-D geometry. In fact, the net flow over the 10,000 year simulation is less with anhydrite fracturing compared the simulation without the beds fracturing. Figure 2.1.4 of the sensitivity analysis report[2] (Figure 3) indicates very little marker bed inflow with microbial gas generation of plastics and

---

[1]Vaughn, P., T. Hadgu, D. McArthur, and J. Schreiber, FEP Screening Analysis S1: Verification of 2-D-Radial Flaring Using 3D Geometry, Memorandum to D.R. Anderson, January 26, 1996, WPO 30840, Sandia National Laboratory, Attachment 4-1 to Appendix Mass of the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, DOE/CAO-1996-2184, December, 1996.

[2]Helton, Jon, Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant, Memo, Sandia National Laboratories, December, 1996.

rubber, supporting the findings of the FEP analysis. Figure 5.1.5 of the sensitivity analysis report reveals the importance to direct brine release of these low brine inflows. The highest pressures are correlated with brine saturations below the residual brine saturation of the waste. The low saturations are due partly to increasing repository pore space with increasing pressure and partly to lower brine inflow.

Table 2.5.13 of the sensitivity analysis report indicates that the potential for anhydrite bed fracturing is high. As a crude approximation, consider the undisturbed scenario of a total fracture-enhanced flow of 20,000 m^3 over a period of 2,000 years. The highest repository pressure in the FEP S-1 calculations was 13 MPa [Correct value is 16.5 MPa]. This corresponds to a repository pore space of 85,000 m^3 (Figure 2.3.5 of the sensitivity analysis report)[at 13 MPa]. The increased brine flow would increase the average brine saturation by 0.23. The CCA calculations do not include simulations of both very high pressure and brine saturations above the residual brine saturation of the waste. Inspection of Figure 5.1.5 suggests a significant impact from a 0.23 saturation shift at high pressures.

The simulations without anhydrite fracturing show a decrease of $1x10^6$ to $2x10^6$ kg (800 to 1,600 m^3) in predicted brine inflow in the 2-D simulations compared to the 3-D simulations(Figure 4; Figure 10 of the FEP S-1 memo). These flows are doubled for the full repository. The differences are most likely from differences in marker beds flows to the repository.

To put these brine inflow differences in perspective, note that average brine inflow to the repository in the CCA calculations of the similar S5 scenario was almost 40,000 m^3, with an average 8,000 m^3 from the marker beds[2]. Marker bed brine flows in the S5 scenario are dominated by flows under low pressure conditions. The marker bed flows are a more significant concern in the S1 undisturbed scenario. An average of roughly 3,000 m^3 flowed into the repository from the marker beds in the S1 CCA calculations. To approximate the brine flow error in the undisturbed calculations for pressures below the anhydrite fracture threshold, we ratio the FEP S-1 differences by 3,000/8,000 - resulting in the range of 600 to 1,200 m^3 less brine inflow to the full repository. If 1,200 m^3 of brine were distributed throughout the entire repository it could increase the average saturations by 0.015 to 0.03 (0.04 to 0.08 in the S5 scenario and 0.16 to 0.32 after anhydrite fracturing in an S5 scenario). It is more likely that much of the additional brine would be consumed through increased gas generation, leading to higher repository pressures.

There are indications in the sensitivity analysis report that the computational grid effects the distribution of brine within the repository in addition to the overall magnitude of brine. One indication is the statement on page 2-26 that "Due to the computational grid in use (Fig. 1.2.1), the lower panel receives more brine inflow from the marker beds relative to its size than the upper waste panels (Fig. 2.1.2)." Another indication may be the importance of the residual gas saturation of the shaft seals to flow through the marker beds (Table 2.1.1 of the sensitivity analysis report). As stated in the report, "its selection may be due to effects related to brine and gas movement across the part of the computational grid that corresponds to the shaft in the repository and DRZ (i.e., regions 10,11 in Fig. 1.2.1)." As a result, the upper waste panels receive roughly one ninth of the brine inflow from the marker beds per panel as the lower waste panel. In a large fraction of the sampled vectors, gas generation stops in the upper panels because of limited brine availability for steel corrosion. Thus, the CCA calculations are under-predicting repository pressure as well as brine saturation.

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 re-examined with appropriate consideration of the impact of increased brine saturation on calculated release estimates.

DOE Response to the EEG Comments

Attached to Letter by GE Dials to L. Weinstock, *DOE Response to Comments made to EPA by EEG on the DOE's CCA Dated March 14, 1997.,* June, 27, 1997.

Brine inflow to the repository

Vaughn et al. justified the use of the 2-D radial-flaring BRAGFLO model by comparing the results of the 2-D model with those of a corresponding 3-D model. However, the limits of the analysis exceeded the highest predicted pressures in the repository by approximately 4 to 5 MPa.

The 2-D and 3-D model results show reasonable agreement, except under conditions where fracturing of the anhydrite beds occurs (at pressures above 12.7 MPa). The 3D model predicted a greater flow of brine into the repository than the 2-D model when the pressure in the repository was sufficient to increase porosity in the fractured anhydrite beds. However, the high constant gas generation rate assumed in the *Vaughn et al.* analysis resulted in peak average pressures in the repository of about 17.5 MPa (2-D BRAGFLO) and 16.5 MPa (3-D BRAGFLO) *(Vaughn et al.*, Figure 11) (not 13 MPa as stated by the EEG), which are greater than the highest pressures expected in the repository (see *Helton*, Figure 2.3.2). Thus, the large increases in average anhydrite porosity and associated brine inflow predicted by 3DBRAGFLO are not likely to occur in the repository.

Vaughn et al. assumed constant gas generation rates with no brine consumption. In reality, any additional brine entering the repository would likely be consumed by gas generation processes, which would limit brine saturation. PA calculations show that significant

amounts (at least 409G of the initial inventory) of uncorroded iron will persist throughout the lO,OOO year regulatory period under conditions of undisturbed performance (CCA Figure 9-10). The extent of corrosion is limited by the amount of brine available, and the iron inventory will not be exhausted as a result of the increase in brine flow to the repository predicted by 3D-BRAGFLO. Subsequent to an intrusion the pressure within the repository is relieved and remains below the fracture initiation pressure.
EEG acknowledges that higher brine saturations would not necessarily occur as a result of increased brine flow to the repository, but that increased brine flow would lead to increased gas generation. Increased volumes of gas generated at high pressures (above 12.7 MPa) would tend to result in increased porosity in the fractured anhydrite rather than significant increases in pressure. *Helton* (Figure 2.3.1) showed that repository pressures do not increase greatly above 12.7 MPa (after fracturing has occurred).

Pressures sufficiently high to cause fracturing (12.7 MPa) tend to occur at low brine saturations (*Helton* Figure 5.1.5) due to the consumption of brine by corrosion. If brine inflow occurs at the high pressures suggested by the 3-D BRAGFLO analysis (in excess of 16.5 MPa), then brine saturation in the repository could increase. The EEG suggests that brine saturation could increase by as much as 23 % at such pressures. However, as discussed above, this value of pressure is unrealistically high given that gas generation processes could consume most of any additional brine entering the repository. Nonetheless, even with the unrealistic assumption that brine saturation increases by 23%, Figure 5.1.5 of Helton shows that the number of simulations in which direct brine release resulting from a drilling intrusion occurs would not increase significantly. Although accounting for higher brine saturations could increase cumulative direct brine releases, the overall CCDFs from all release pathways would be little changed because of the relatively minor contribution of direct brine release to overall releases (CCA Figure 641).

In summary, the set of conditions where the 3D-BRAGFLO and 2D-BRAGFLO do not show good agreement (average pressures above 16 MPa) are not expected to occur in the repository. Even if such pressures did occur, resulting in anhydrite fracturing and porosity increase, the brine inflow predicted by 3D-BRAGFLO would have little effect on direct brine release during a drilling intrusion.

EPA Response to Comment # 553

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 FEPs 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.

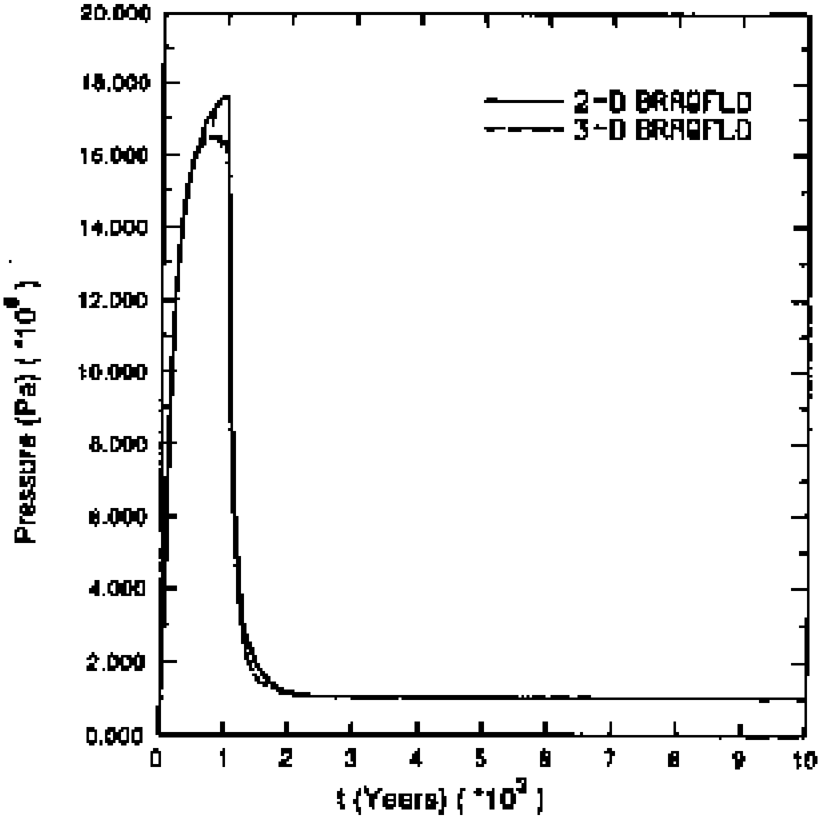


Figure 1: Average Pressure in Repository, FEP S-1 Analysis
From Vaughn et al, 1996.

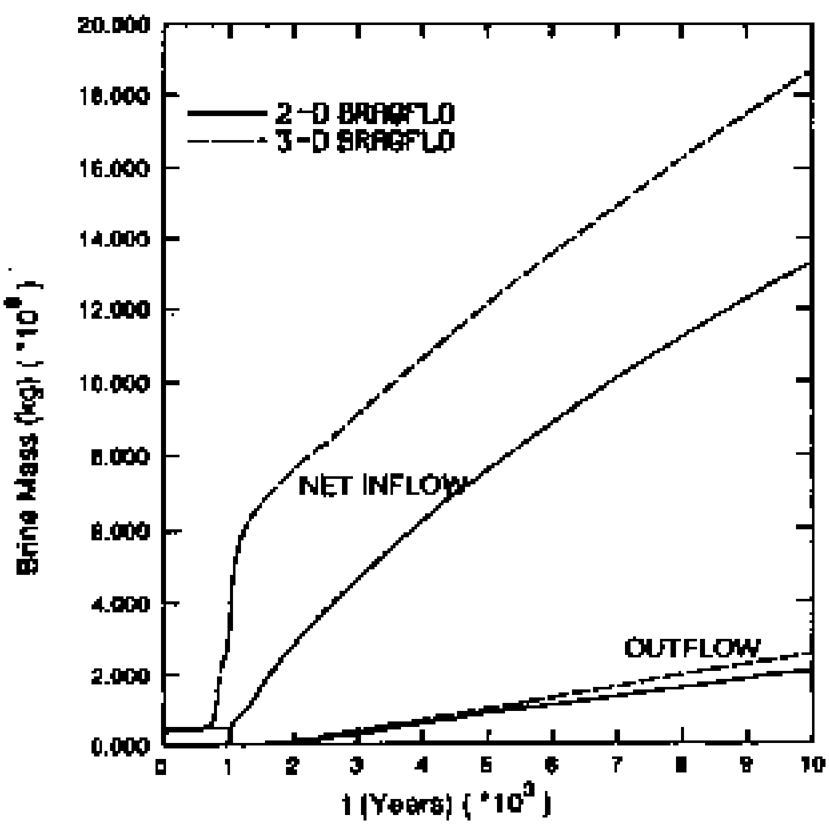


Figure 2: Cumulative Net Brine in and outflow at Repository, FEP S-1 Analysis
From Vaughn et al, 1996.

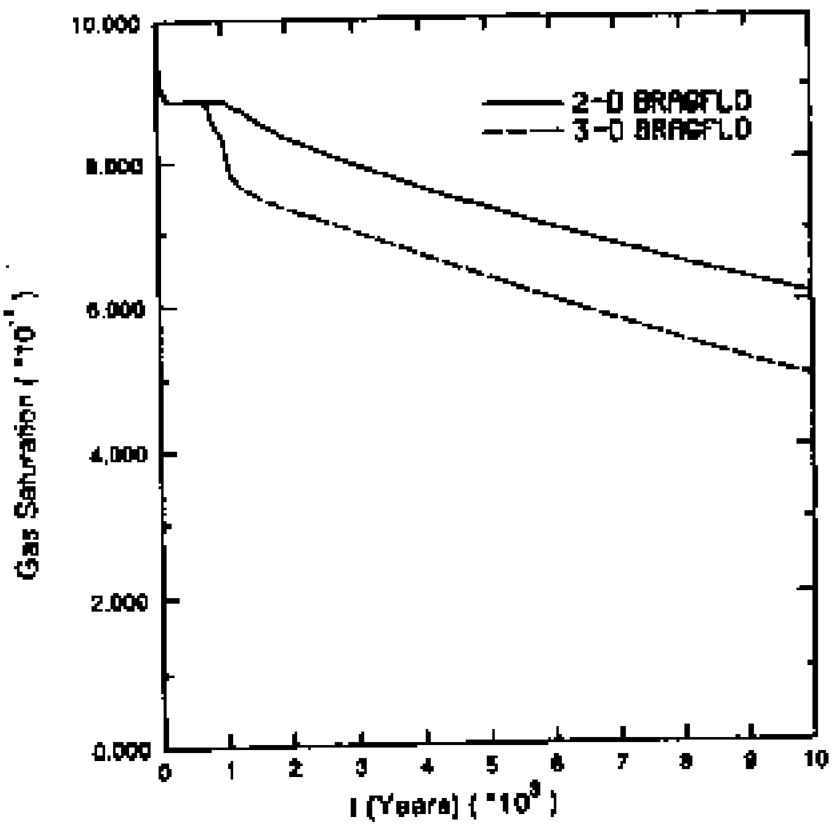


Figure 3: Average Gas Saturation in Repository, FEP S-1 Analysis
From Vaughn et al, 1996

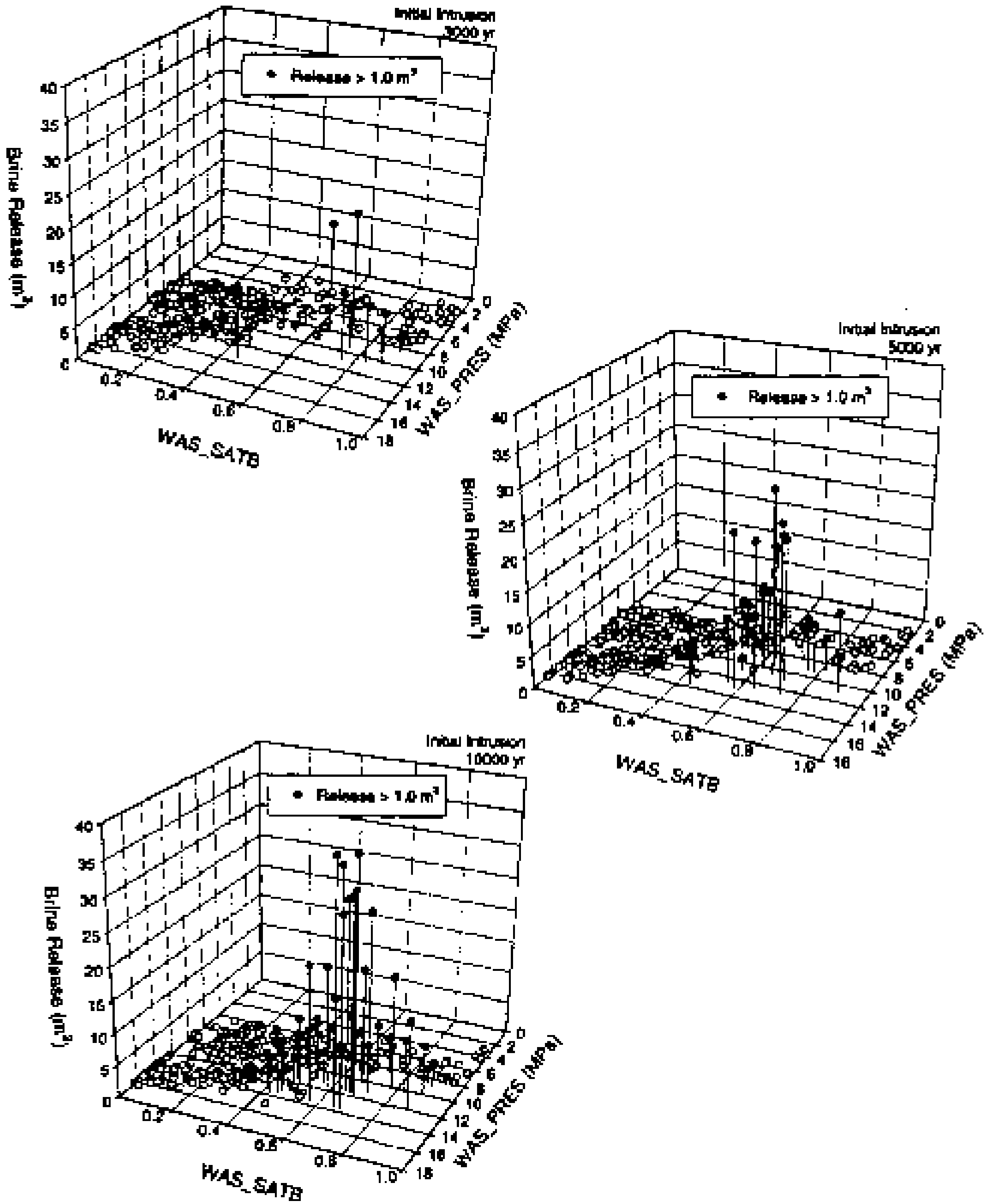


Figure 4: Three dimensional scatter plots for volume of brine reaching the surface due to direct brine release for a drilling intrusion into the lower panel.
From Helton, 1996.

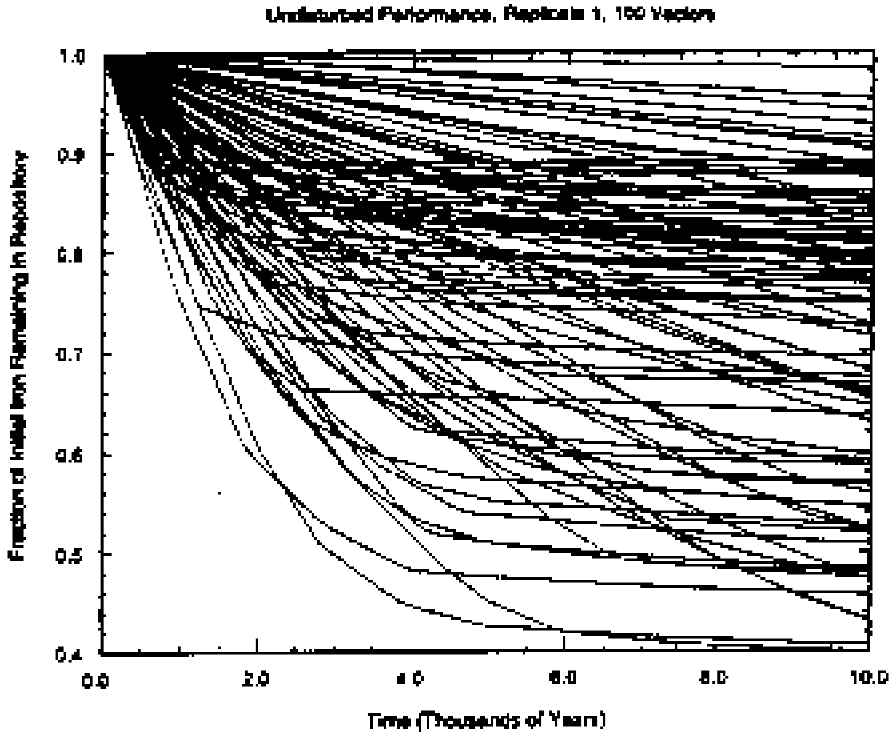


Figure 5: Fraction of Initial Iron Remaining in Repository
From: DOE, 1996.

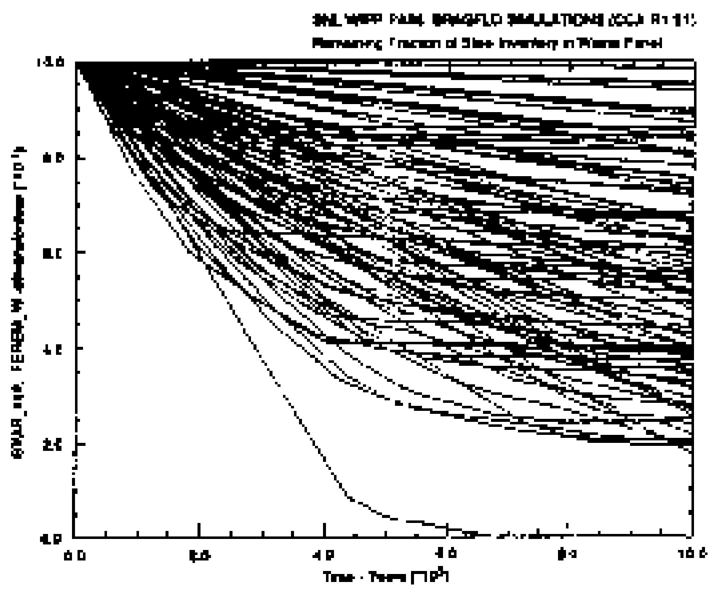


Figure 6: Remaining Fraction of Steel Inventory in Waste Panel
Modified from Figure 2.2.9 in Helton, 1996.

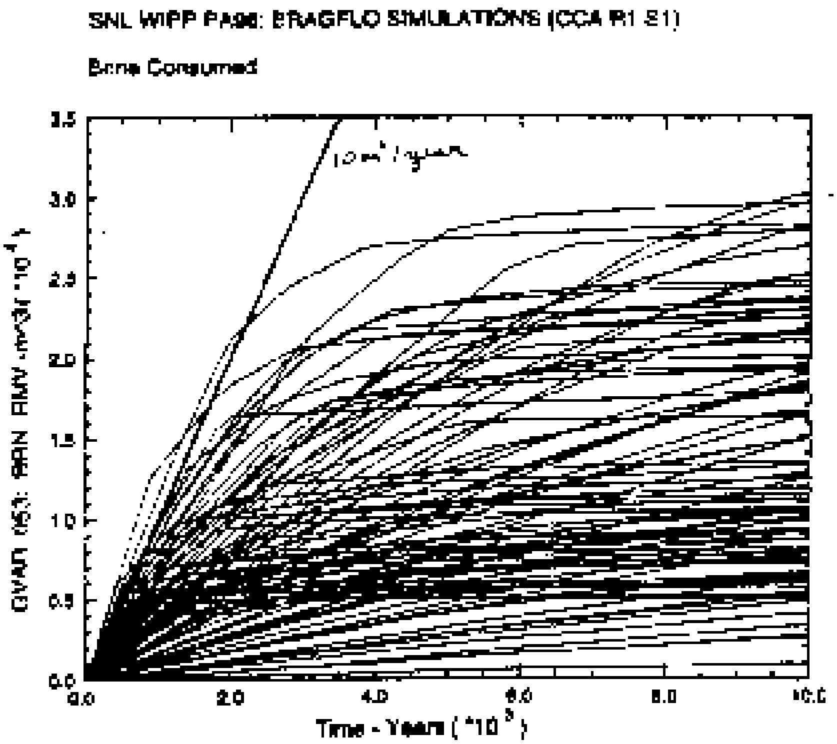


Figure 7: Cumulative Volume of Brine Consumed by Corrosion in the Repository Modified from: Helton, 1996.

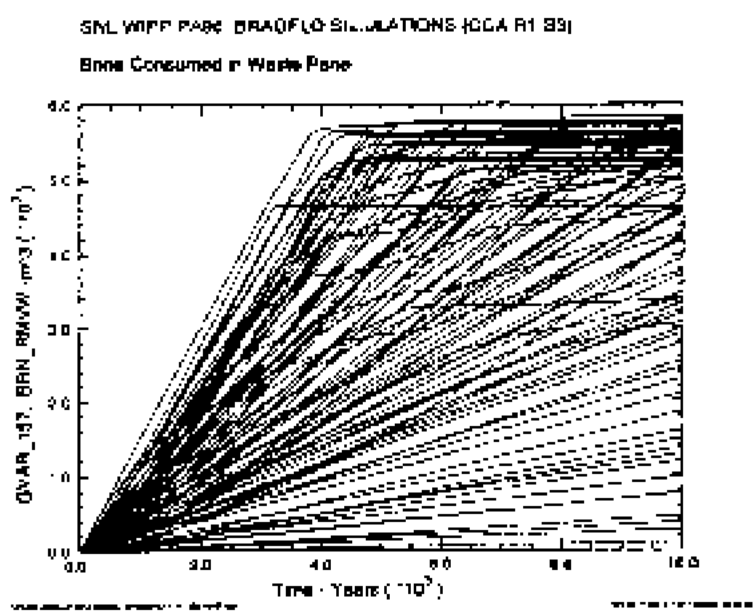


Figure 8: Cumulative Volume of Brine Consumed in the Waste Panel From Bean et al., 1996

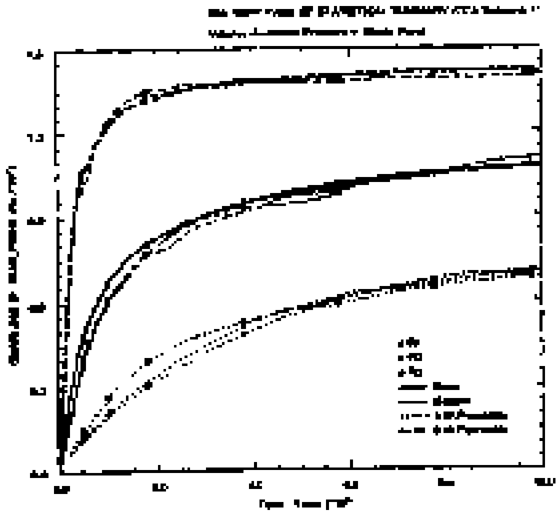


Figure 9: Percentile curves for three replicated LHSs for pressure in waste panel
From: Helton, 1996.

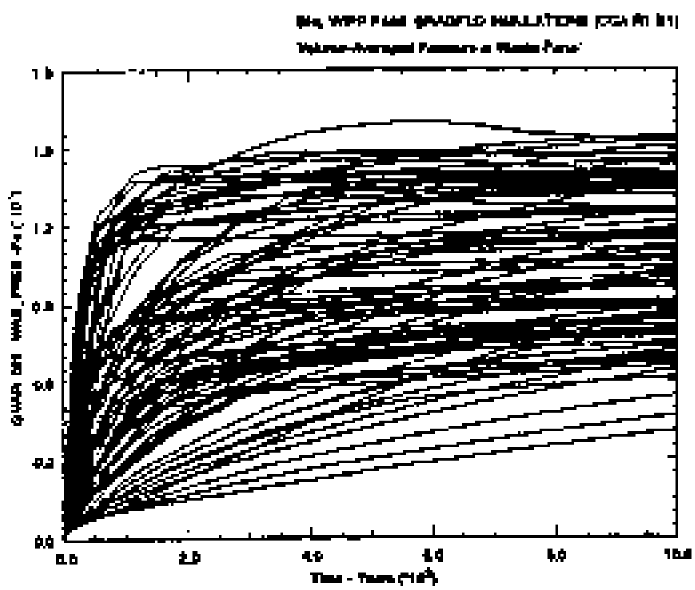
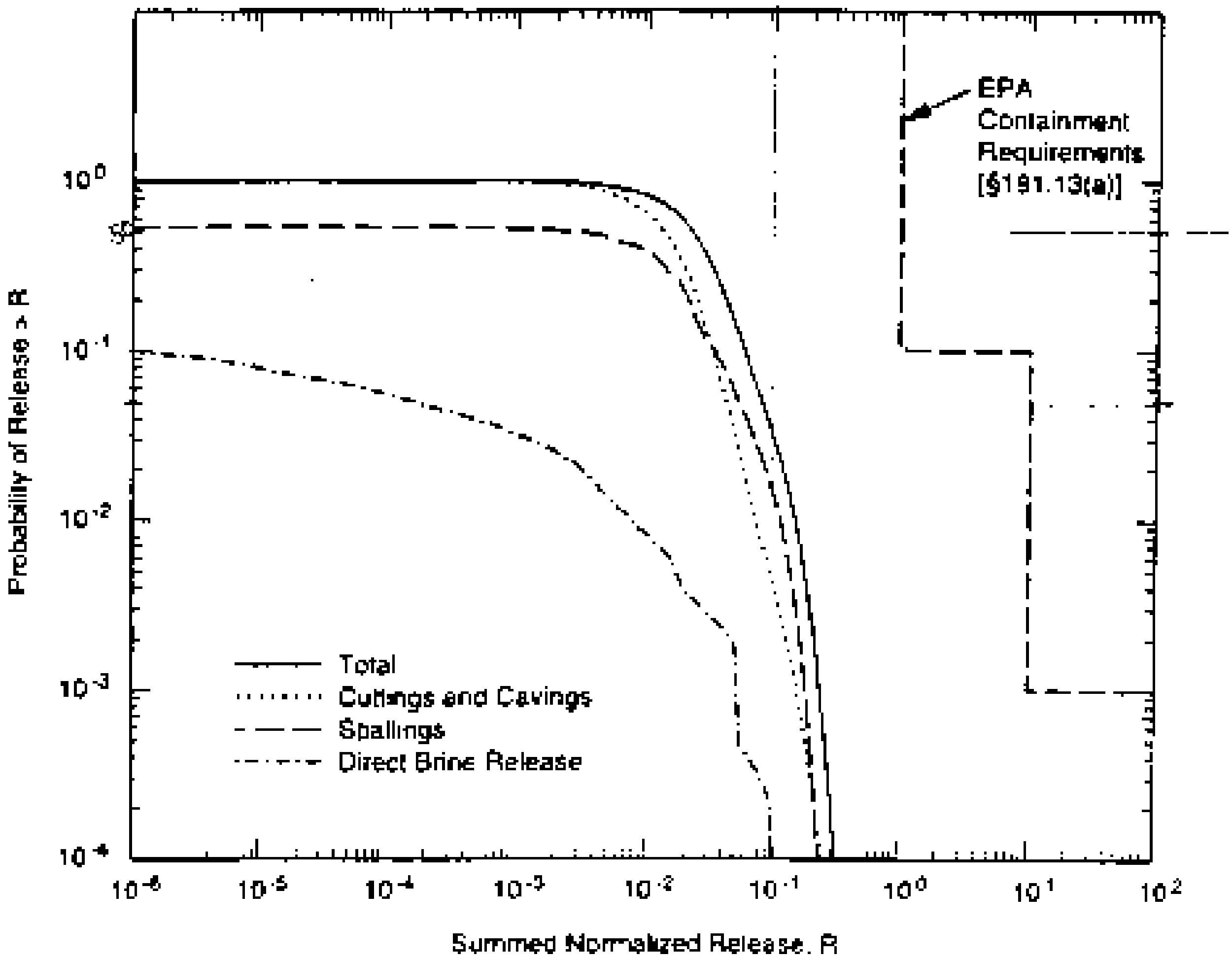


Figure 10: Pressure in waste panel
Modified from Figure 2.3.1 of Helton, 1996.



Note Mean CCDFs are shown for the total normalized release (this curve is also shown in Figure 6-40 and is the mean of the family shown in Figure 6-35) and for the normalized releases resulting from cuttings and cavings, spallings, and direct brine release. The mean CCDF for subsurface releases resulting from groundwater transport is not shown because those releases were less then 10-6 EPA units and the CCDF cannot be shown at the scale of this figure

Figure 11: Mean CCDFs for Specific Release Modes, Replicate 1. From DOE, 1996.

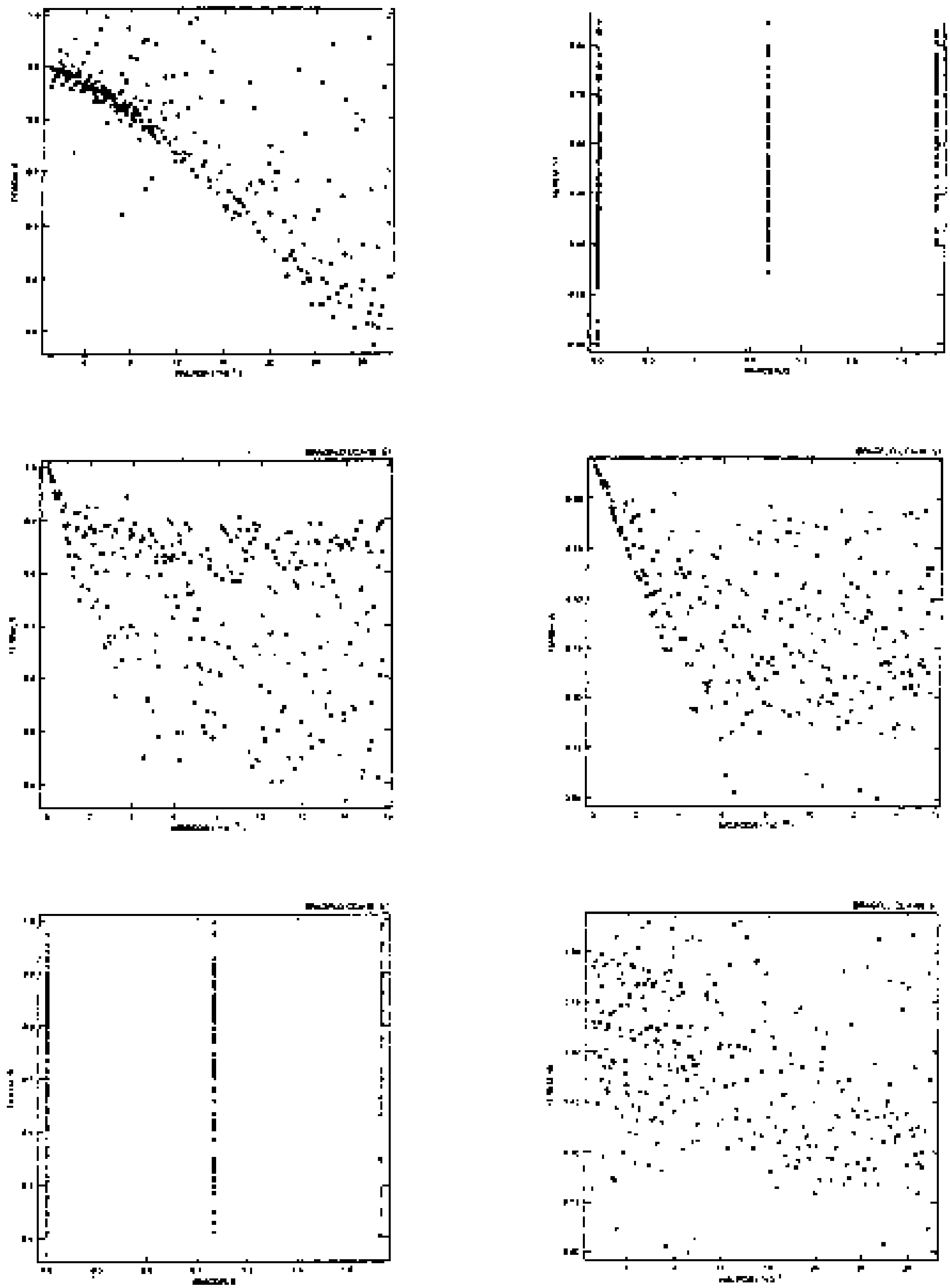


Figure 12: Scatter Plots of the Fraction of Iron Remaining in the Waste Panel (Right Frames) and Rest of the Repository (Left Frames) for Undisturbed Conditions at 10,000 Years.
From Helton, 1996.

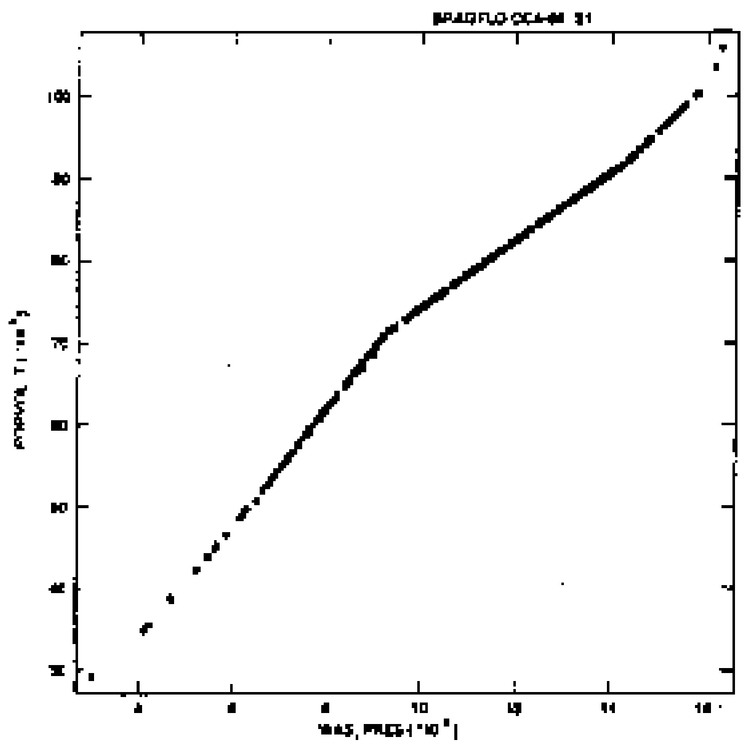


Figure 13: Scatter plot of pressure versus total pore volume in the repository. From Helton, 1996.

Table 1: Stepwise Regression Analysis with Rank-Transformed Data for Pressure in the Waste panel at 10000 years. From Helton, 1996.

Step[a]	Variable[b]	SRRC[c]	R^2[d]
1	*WMICDFLG*	0.71	0.52
2	*HALPOR*	0.45	0.73
3	*WGRCOR*	0.23	0.79
4	*ANHPRM*	0.11	.080
5	*SALPRES*	0.07	0.80
6	*SHRGSSAT*	0.06	0.81

[a] Steps in stepwise regression analysis.

[b] Variables listed in order of selection in regression analysis with *ANHCOMP* and *HALCOMP* excluded from entry into regression model.

[c] Standardized regression coefficients in final regression model.

[d] Cumulative R^2 value with entry of each variable into regression model.

Table 2: Stepwise Regression Analysis with Rank-Transformed Data for Fraction of Steel Remaining and Total Gas Generation in Upper and Lower Waste Panels at 10000 years. From Helton, 1996.

	Fraction Steel Remaining Upper Waste Panels			Fraction Steel Remaining Lower Waste Panels			Total Gas Generation Upper Waste Panels			Total Gas Generation Lower Waste Panels		
Step[a]	Variable[b]	SRRC[c]	R^2[d]	Variable	SRRC	R^2	Variable	SRRC	R^2	Variable	SRRC	R^2
1	*HALPOR*	−0.74	0.63	*WMICDFLG*	0.46	0.20	*WMICDFLG*	0.65	0.43	*WGRCOR*	0.47	0.23
2	*WGRCOR*	−0.35	0.75	*WGRCOR*	−0.45	0.41	*HALPOR*	0.58	0.77	*HALPOR*	0.45	0.44
3	*WMICDFLG*	0.12	0.76	*HALPOR*	−0.38	0.56	*WGRCOR*	0.24	0.83	*ANHPRM*	0.33	0.55
4	*WASTWICK*	−0.10	0.77	*ANHPRM*	−0.25	0.63	*WASTWICK*	0.07	0.83	*WMICDFLG*	0.17	0.58
5	*SHRGSSAT*	−0.08	0.78	*HALPRM*	−0.09	0.67	*SHRGSSAT*	0.06	0.83	*HALPRM*	0.12	0.59
6	*RPINTPRS*	−0.06	0.78	*SHRGSSAT*	−0.09	0.64				*SHRGSSAT*	0.08	0.60

[a] Steps in stepwise regression analysis.

[b] Variables listed in order of selection in regression analysis with *ANHCOMP* and *HALCOMP* excluded from entry into regression model.

[c] Standardized regression coefficients in final regression model.

[d] Cumulative R^2 value with entry of each variable into regression model

(Enclosure 3 to the 12/31/97 Letter From R.H. Neill, EEG to F. Marcinowski, EPA)

Issue: Compliance Failure as a Result of Spalled Material Reaching the Accessible Environment

Introduction

The issue of spalled material reaching the accessible environment at the WIPP has undergone much research within the past few years (Berglund, 1994; DOE, 1996; Hansen et al., 1997). Spall is the mechanical failure of waste due to high repository gas pressures that could be induced by a drop in pressure from a drilling intrusion. This process of waste removal has been included in the Performance Assessment calculations of the CCA. Yet, the amount that will actually reach the surface it is still unclear. Spallings are very important to the compliance of the disposal system, because the large release of radionuclides in the spalled material may prove the repository to be unsafe to future generations.

The three mechanisms of spall include blowout, stuck pipe and gas erosion, with the latter two being eliminated from calculations at the WIPP. It has been estimated that stuck pipe and gas erosion could bring more waste to the surface than blowout (Berglund (1994)). Blowout is the removal of the drilling fluid from the wellbore from a high influx of gas into the spalled cavity. The gas will cause some of the waste material on the cavity walls to fail in tension and be transported to the surface. High repository pressures and high waste permeability are general repository conditions for blowout.

Stuck pipe is a process of spall that, due to relatively low permeability and high repository pressures, may cause failed waste to press against the drill string sufficiently hard to prevent normal drilling. The solution of 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. Gas erosion describes spall that is eroded by the drilling mud and may occur due to high repository pressures and low waste permeability. The rate of spall is slower than stuck pipe due to slightly lower pressures than stuck pipe (just above hydrostatic), and may release waste into the drilling mud at a rate undetectable by the driller. Gas erosion could continue until the repository pressure is in equilibrium with the drilling fluid, and may also bring significant quantities of waste to the surface. Stuck pipe and gas erosion releases would occur if the waste permeability is less than 10^{-16} m^2, a permeability threshold defined in Berglund (1994) that is currently under question, and repository pressures are greater than the pressure exerted by the drilling mud.

As part of the performance assessment, blowout calculations were performed, and volumes of failed waste material were estimated for the CCA, which ranged from 0.5 m^3 to 4 m^3. However, these calculations were found to be faulty by the DOE's Conceptual Model Peer Review Group (Wilson et al., 1997), and a new model for blowout was developed (Hansen et al., 1997). The new model showed that the CCA predicted blowout releases were conservative, by estimating a maximum release of only 0.27 m^3 at the worst conditions of repository behavior.

Through an investigation of permeability of the new spallings model, it is questionable whether the calculations of blowout is sufficient in estimating releases to the surface. The model was run with a range of permeability values consistent with Hansen et al., (1997), and was found to have high volumes of failed material in the repository cavity when gas influx was insufficiently large to cause blowout. Though blowout had not occurred, the failed waste in the borehole cavity would be introduced into the drilling mud and be carried to the surface with other cuttings and cavings from borehole drilling activity. This defines gas erosion and was not considered in Hansen et al., (1997).

More important to the question of the amount of waste released to the surface that will be expelled from the pressurized repository, is the amount of spalled material that will cause the repository to fail compliance. The performance assessment calculations of the CCA (DOE, 1996) and PAVT (DOE, 1997) demonstrated that any combination of spalled releases from blowout from 0.5 m^3 to 4 m^3 will demonstrate compliance. However, no one, as of yet, looked at the issue of failure. This report investigates the amount of spalled material that would result in failure to meet the EPA compliance standards.

Discussion

For the performance assessment calculations of the PAVT, the EPA decided to sample blowout releases on a range from 0.5 m^3 to 4.0 m^3 with a uniform distribution assigned to that range. The result was an increase in the overall mean of releases for spallings in the CCDF from 0.04 EPA units at the 10^{-1} probability in the CCA to 0.08 EPA Units in the PAVT. The increase was also due to the number of vectors that exhibited pressures above hydrostatic. The spallings and cuttings portions of the CCDF contribute equally to the overall mean of the CCDF.

For a more complete view of spallings and its contribution to the overall mean of the CCDF, the values of 0.5 to 4 m^3 used in the PAVT calculations were increased by a factor until it was shown that there was failure of compliance. The factor ranged from 2 to 16, and was a very simple adjustment to the PAVT values.

The results of increased spall reaching the surface can be seen in Figure 1. The increase in spall was accomplished by multiplying the PAVT generated releases by a factor of 2, 4, 8, and 16. These curves are seen in Figure 1, and are compared to the CCA releases. The figure suggests that a maximum of 16 times the amount of spallings will cause the repository to fail at the 10^{-1} probability, which corresponds to spallings releases between 8 m^3 and 64 m^3.

Conclusion

The questions raised on the amount of spalled material that will cause the disposal system to fail compliance is addressed here. The concern of additional spalled material that may reach the surface, by either a stuck pipe / gas erosion process, or through air drilling can be seen in Figure 1. The figure shows that a maximum of 16 times the PAVT spalled release can be brought to the surface before compliance of the disposal system is compromised if other modes of releases are held constant.

References

Berglund, J.W., 1994. Memorandum to Record “The Direct Removal of Waste Caused by a Drilling Intrusion Into a WIPP Panel-A Position Paper.” Albuquerque, NM. Sandia National Laboratories, WPO# 9882.

Hansen, F.D., Knowles, M.K., Thompson, T.W., Gross, M., McLennan, J.D., Schatz, J.F., 1997. Description and Evaluation of a Mechanistically Based Conceptual Model for Spall. Sandia National Laboratories, SAND97-1369. Albuquerque, NM.

U.S. Department of Energy, 1996. Title 40 CFR 191 Compliance Certification Application. DOE/CAO-1996-2184.

U.S. Department of Energy, 1997. Summary of the EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations. EPA Docket A-93-02, II-G-26.

Wilson, C., Porter, D., Gibbons, J., Oswald, R., Sjoblom, G., 1997. Waste Isolation Pilot Plant Conceptual Models Peer Review: Final Report. DOE/CAO-1996-1985. Carlsbad, NM:U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office.

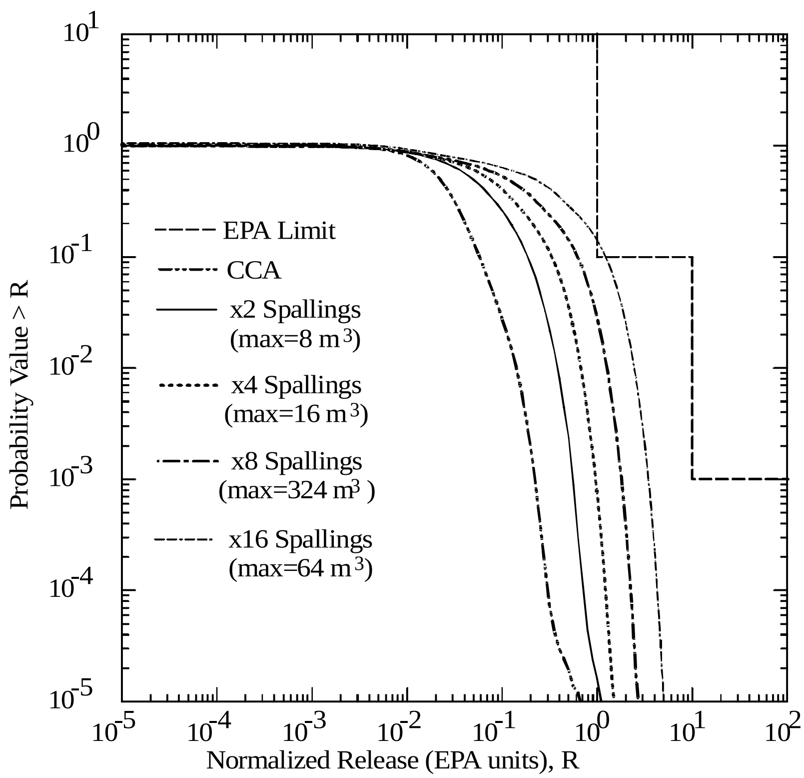


Figure 1: Overall Mean For PAVT Increased Spallings

(Enclosure 4 to the 12/31/97 Letter From R.H. Neill, EEG to F. Marcinowski, EPA)

Issue: Modeling the Air Drilling Scenario through a Direct Brine Release at the WIPP

Introduction

The practice of drilling with air as the circulation fluid in wells has been established in the Delaware Basin. On April 2, 1991 the Lincoln Federal Well No. 1 in Section 26, T21S, R32E, NMPM, in Lea County, New Mexico was drilled with air after 11 days of drilling with mud brine (Silva, 1994; EEG-55 p.63-64). The CCA did not consider the practice of drilling with air as a possible method for well development.

The modeling of air drilling was first raised by Bredehoeft (1997). Bredehoeft addressed the concern of spalled (solid) material that would reach the accessible environment through an air drilling scenario. His results show that a large amount of material could reach the surface, thus breaking the compliance standards set in 40 CFR Part 194 (EPA, 1997). This is the first report to address the issue of contaminated brine released after drilling with air. The issue is studied here, by applying a model to the release of brine through an inadvertent drill intrusion into the WIPP repository.

Discussion

An air drilling scenario is investigated using the Sandia developed code for a brine release through an intruding borehole. The code, BRAGFLO_DBR, is used along with the same assumptions as the Performance Assessment Verification Test (PAVT), including the BRAGFLO output files, and CUTTINGS_S files, but changing the boring fluid from a brine mud to air. The change in boring fluid would decrease the pressure at the bottom of the borehole, thus allowing a higher release of brine to escape to the surface.

For blowout to occur, the pressure of the repository must be higher than the borehole pressure at the repository depth. For brine mud, the pressure is assumed to be hydrostatic, or 8 MPa. For the air column, the air pressure will be very low, and was assumed to be approximately 2 MPa for this model, thus allowing higher and more frequent blowout occurrences than higher pressures. The 2 MPa is assumed to approximate the pressure exerted by a foam/air mixture at the depth of the WIPP repository. Air alone would exert pressures far below that of foam/air combination. However, this cutoff is reasonable due to the extremely low number of vectors that are expected to fall below the 2 MPa cutoff. One additional change from the PAVT for modeling with air includes the density of the drilling fluid from 1215 kg/m^3 for brine to 1.161 kg/m^3 for air.

The model was run for an initial E1 intrusion at 350 and 1000 years, and subsequent E2 intrusions at 550, 750, 1200, 1400, 2000, 3000, 4000, 5000, and 10000 years post closure (S2 and S3 scenarios). The results, shown in Figure 1, demonstrates the danger of drilling with air into the repository. The figure shows the results of 100 vectors for time 1200 years for S3, Replicate 1 using air as the drilling fluid. A single realization is shown to release as much as 2400 m^3 of brine to the surface at a second intrusion time of 1200 years. This is the highest brine release seen for all vectors at all times. The mean value for all releases at 1200 years is 436 m^3. The PAVT results show a maximum of 76 m^3 at 1200 years postclosure (DOE, 1997), and the CCA predicted a maximum release of 15 m^3 (DOE, 1997).

The high volumes of release seen in Figure 1 can be attributed to the high pressures of the repository. At 1200 years postclosure, the repository pressure of vector 51, which has the highest releases, exceeds most other vectors at 13.3 MPa, and is ranked 4th out of 100 vectors for highest repository pressure. Also contributing to its high release is the waste saturation. Vector 51 has a saturation of 0.67, which has been seen in past sensitivity analyses (See Figure 5.1.5. of Helton, 1996) to be an ideal saturation for release.

Inherently, there are problems with using the BRAGFLO_DBR code this way. The model assumed an incompressible fluid in the wellbore. Air is compressible, and the effects of incompressibility on the releases are not known. There are also some questions of whether the drilling fluid density change affected the whole repository or just the wellbore. This was a quick experiment, and these questions will be investigated further by the EEG. However, the results seen in Figure 1 are believed to provide an indication of the magnitude of potential releases.

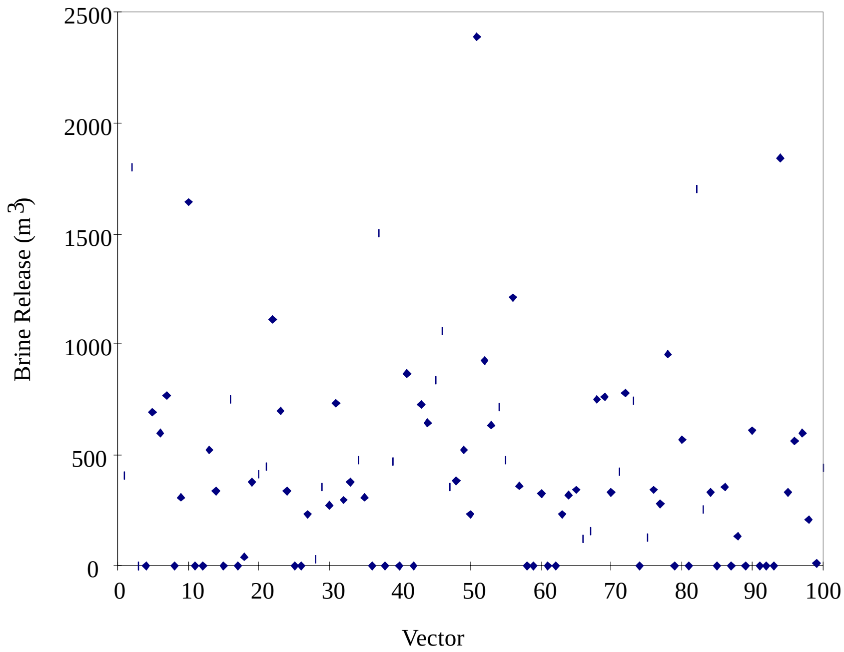


Figure 1. Air Drilling Results for 100 vectors of an S3 scenario at 1200 years postclosur

The carrying capacity of the brine to transport radionuclides to the surface depends on the solubility of the actinides in solution. The CCA's median value of solubility for a +4 actinide (Plutonium (IV), Uranium (IV), or Thorium (IV)) in Salado brine is approximately 4e-6 M. Thus, calculating the number of grams of Plutonium-239 (IV) for 2400 m^3 of brine is 2300 g. The grams can be converted to activity, and the 2400 m^3 of brine can be calculated to carry 140 Ci, or 0.4 EPA units. Higher solubility values will result in higher releases to the surface.

The CCDF curves, using the results of air drilling, can be seen in Figure 2. The code, which produced the curves, used the releases from PAVT and solubilities from the CCA. The direct brine release results of air drilling were then substituted for the results of the PAVT. Again, it should be noted that the CCDF results use spallings releases calculated in the PAVT. Spallings releases due to an air drilling event were not incorporated into the results. These curves assume a worst case scenario, in which all the drilling from an E1E2 drilling event would be using air as the drilling fluid.

In addition to the CCA solubilities, actinide solubilities with different mineral species were included. The solubilities were from median values using Nesquehonite, a mineral phase of the magnesium carbonate system, and from no MgO backfill. The 'No Backfill' case does not suggest that MgO should not be present in the repository, but gives an upper bound on solubility and how it affects compliance to the EPA standards. Table 1 shows the values used for each actinide oxidation state.

The CCDF curves for CCA solubility values do not exceed the EPA standard at the 10^{-1} or 10^{-3} probability level. Yet, the issue should not be readily dismissed. The problem was run on the scenarios of S2 and S3 only. The other three scenarios assumed brine mud as the drilling fluid. Furthermore, solubility values are shown to be greater in other mineral species of the magnesium carbonate system, and if the repository is breached during a time when these minerals will dominate the repository, then there may be sufficient releases to the accessible environment to cause the repository to fail compliance. This example can be seen in the curve for the Nesquehonite solubility. Again, this is a worst-case scenario in which all vectors for the simulation of air drilling uses the median values for Nesquehonite solubility, which can be seen in Table 1. The curve for Nesquehonite crosses the EPA compliance limit at the 0.02 probability level. This relates to a 1 in 50 chance of releasing more than 3500 Ci to the surface. The curve drops to a 1 in 500 chance of releasing more than 35000 Ci to the surface.

Salado	**+3 (M)**	**+4 (M)**	**+6 (M)**
Nesquehonite	3.17e-7	6.3e-4	NA (used No Backfill)
No Backfill	4e-3	5e-4	8e-5
Castile			
Nesquehonite	2.4e-6	1.04e-3	NA (used No Backfill)
No Backfill	2e-3	7e-5	8e-5

Table 1. Solubility values used in PANEL for generation of CCDF curves.

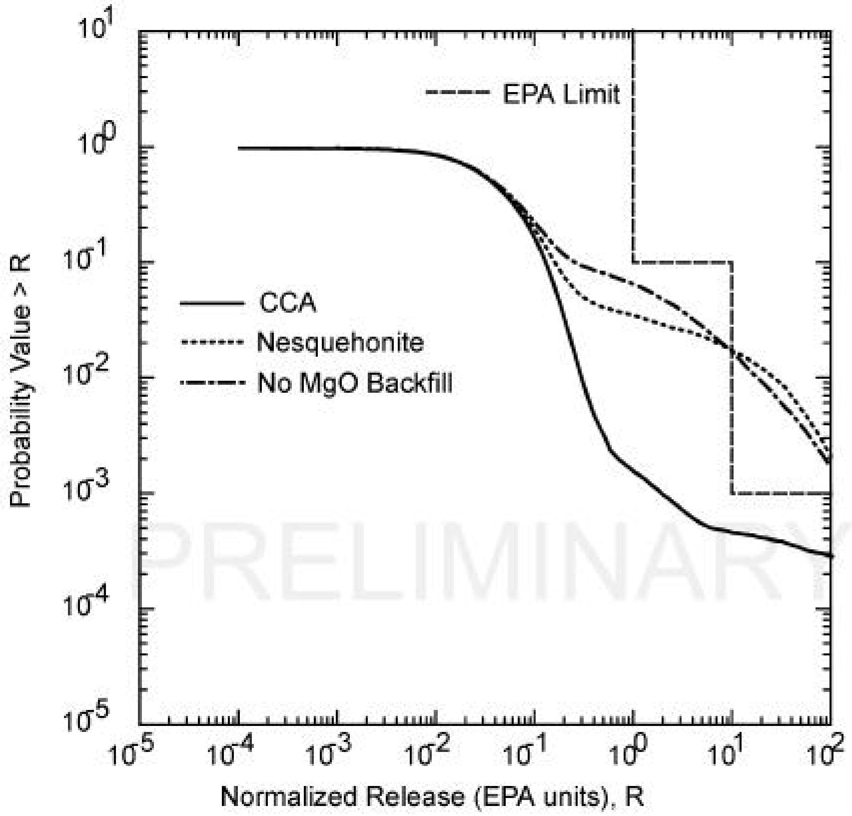


Figure 2. CCDF for Air Drilling with different solubilities. Air Drilling Modeling only included Direct Brine Releases for S2 and S3. Cuttings, spallings, and transport through the Culebra results are from PAVT, with actinide solubility values from the CCA, formation with Nesquehonite, and no MgO backfill.

The third curve on the CCDF plot shows the response of the disposal system for solubility values from 'No MgO Backfill'. The releases for probabilities greater than 1 in 50 are much higher than the other two curves. However, at lower probabilities the 'No MgO Backfill' has lower releases than the solubilities with Nesquehonite. This is due to the difference in solubility values at the +4 oxidation state for both Salado and Castile brine. In conclusion, the CCDF curves are shown to cross the EPA Release limits for higher solubility values, and the issue of air drilling must be taken more seriously than previous evaluations.

Recommendations

1) The EPA should look more closely at the issue of air drilling to determine the probability of such an event occurring in the 10000 year projected history of the disposal system.
2) EPA needs to asses the appropriateness of using the BRAGFLO direct brine release model for air drilling.
3) Depending on EPA's resolution of the solubility issue, the EPA may need to calculate CCDFs for air drilling.

Reproducibility

To reproduce the results of this experiments, the summarized files (*.TBL) of CUTTINGS_S, BRAGFLO_DBR, and SECOTP2D from PAVT, and the summarized files of NUTS, PANEL, and ST (Source Term) from the CCA are needed for the input for CCDFGF. In addition, the BRAGFLO_DBR files from an air drilling scenario will replace some of the BRAGFLO_DBR of the PAVT. Attachment 1 shows the input for the preprocessor of CCDFGF. The Direct Brine Release summarized files begin with: 'SUM_BF4_CCGF_AIR'.

The simulation of drilling with air with BRAGFLO_DBR was accomplished by changing the inputs to the preprocessor of the model. The ALGEBRA file 'ALG_BF4_CCA_PRE_DIR_REL_S3_DIST.INP' was modified to allow a lower threshold of pressure from the drilling fluid for time stepping. The file sets the time step for the BRAGFLO_DBR to 0 if the flowing bottomhole pressure (FBHP) is less than the pressure of the drilling fluid column, and to a maximum 1000 time steps if the pressure is greater. The FBHP was established in the preprocessor by a 3D curve fit from the Poettmann-Carpenter correlation (DOE, 1996). The ALGEBRA file was also modified for drilling fluid density. Attachment 2 lists the file and highlights the areas of change. The original ALGEBRA file used 8 MPa as the cutoff for timestep configuration. The new model sets the cutoff at 2 MPa.

References

Bredehoeft, J., 1997. Air Drilling Spallings Report. Draft Report of The Hydrodynamics Group. La Honda, CA.

Helton, 1996. Preliminary Summary Of Uncertainty And Sensitivity Analysis Results Obtained In Support Of The 1996 Compliance Certification Application For The Waste Isolation Pilot Plant. Memo, Dec. 23, 1996. Sandia National Laboratories, Albuquerque, NM. SAND 96-2226.

Silva, M.K., 1994. Implications of the Presence of Petroleum Resources on the Integrity of the WIPP. Albuquerque, NM: Environmental Evaluation Group, EEG-55.

U.S. Department of Energy, 1996. Analysis Package for the BRAGFLO Direct Release Calculations (Task 4) of the Performance Assessment Analyses Supporting the Compliance Certification Application. Sandia National Laboratories, Albuquerque, NM. WPO#40520.

U.S. Department of Energy, 1997. Summary of the EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations. EPA Docket A-93-02, II-G-26.

U.S. Environmental Protection Agency, 1997. Title 40 CFR Part 194 Criteria for the Certification and Recertification of the waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Proposed Rule.

Attachment 1: Input for CCDFGF Preprocessor Mode for Air Drilling

```
$!
$! MODULE:      PREPRO.COM
$! PURPOSE:     RUN PREPROCESSOR CODE TO CREATE CUTTINGS, SPALLINGS
$!              BLOWOUT, NUTS, AND SECOTP INPUT TABLES FOR USE BY
$               CCDFGF PREPROCESSOR OPTION
$! ---
$! AUTHOR:      JAY D. JOHNSON
$! DATE:        11/22/96
$!
$! Date         Changes
$! 11/10/97     Solubility      -D. Rucker
$!               CCA denotes CCA Solubilities
$!              EEG2 denotes Nesquehonite Solubilities
$!              EEG1 denotes No Backfill Solubilities
$!
$! 12/3/97      Air Drilling    -D. Rucker
$!              Direct Brine Release: 'SUM_bf4_ccgf_air'.tbl
$! ---
$! Setup for run
$ SET NOON
$ REP := "R2"
$!
$ Testdir1 := "t4:[dfrucke.ccdfgf]"
$ Testdir2 := "t4:[dfrucke.ccdfgf.input_'REP']"
$ Testdir2a:= "t4:[dfrucke.pavt]"
$ Testdir3 := "t4:[dfrucke.ccdfgf.input_'REP']"
$ Testdir3a:= "t4:[dfrucke.pavt]"
$ Testdir4 := "t4:[dfrucke.ccdfgf.input_'REP']"
$ Testdir5 := "t4:[dfrucke.ccdfgf.input_'REP']"
$ Testdir6 := "t4:[dfrucke.panel.con]"
$ Testdir6a := "t4:[dfrucke.panel.time]"
$ Testdir7 := "t4:[dfrucke.cusp]"
$ Testdir8 := "t4:[dfrucke.dbr]"
$ testdir9 := "t4:[dfrucke.nuts]"
$ testdir0 := "t4:[dfrucke.st]"
$ Outdir   := "t4:[dfrucke.ccdfgf]"
$! ---
$! Define CUTTINGS file names
$! ---
$ DEFINE/NOLOG HT_FRAC$INP                 'TESTDIR1'CCGF_CCA_HT_FRAC.DAT
$ DEFINE/NOLOG EPAUNI_CCH$INP              'TESTDIR1'EPU_CCGF_CCA_CCH.DAT
$ DEFINE/NOLOG EPAUNI_CRH$INP              'TESTDIR1'EPU_CCGF_CCA_CRH.DAT
$ DEFINE/NOLOG SUM_CUSP_CCGF_CCA$INP       'TESTDIR2a'SUM_CUSP_C97_'rep'_S1_L_T5000.TBL
$ DEFINE/NOLOG CCGF_CUTTINGS$OUT           'OUTDIR'CUTTING.TRN
$! ---
$! Define SPALLINGS file names
$! ---
$ DEFINE/NOLOG CH_TRU$INP                  'TESTDIR1'CCGF_CCA_CH_TRU.DAT
$! ---
$ DEFINE/NOLOG CUSP_S1_L_T100$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T100.TBL
$ DEFINE/NOLOG CUSP_S1_L_T350$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T350.TBL
$ DEFINE/NOLOG CUSP_S1_L_T1000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T1000.TBL
$ DEFINE/NOLOG CUSP_S1_L_T3000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T3000.TBL
$ DEFINE/NOLOG CUSP_S1_L_T5000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T5000.TBL
$ DEFINE/NOLOG CUSP_S1_L_T10000$INP        'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_L_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S1_U_T100$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T100.TBL
$ DEFINE/NOLOG CUSP_S1_U_T350$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T350.TBL
$ DEFINE/NOLOG CUSP_S1_U_T1000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T1000.TBL
$ DEFINE/NOLOG CUSP_S1_U_T3000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T3000.TBL
$ DEFINE/NOLOG CUSP_S1_U_T5000$INP         'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T5000.TBL
$ DEFINE/NOLOG CUSP_S1_U_T10000$INP        'TESTDIR2a'SUM_CUSP_C97_'REP'_S1_U_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S2_L_T550$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_L_T550.TBL
$ DEFINE/NOLOG CUSP_S2_L_T750$INP          'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_L_T750.TBL
```

```
$ DEFINE/NOLOG CUSP_S2_L_T2000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_L_T2000.TBL
$ DEFINE/NOLOG CUSP_S2_L_T4000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_L_T4000.TBL
$ DEFINE/NOLOG CUSP_S2_L_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_L_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S2_U_T550$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_U_T550.TBL
$ DEFINE/NOLOG CUSP_S2_U_T750$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_U_T750.TBL
$ DEFINE/NOLOG CUSP_S2_U_T2000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_U_T2000.TBL
$ DEFINE/NOLOG CUSP_S2_U_T4000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_U_T4000.TBL
$ DEFINE/NOLOG CUSP_S2_U_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S2_U_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S3_L_T1200$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_L_T1200.TBL
$ DEFINE/NOLOG CUSP_S3_L_T1400$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_L_T1400.TBL
$ DEFINE/NOLOG CUSP_S3_L_T3000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_L_T3000.TBL
$ DEFINE/NOLOG CUSP_S3_L_T5000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_L_T5000.TBL
$ DEFINE/NOLOG CUSP_S3_L_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_L_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S3_U_T1200$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_U_T1200.TBL
$ DEFINE/NOLOG CUSP_S3_U_T1400$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_U_T1400.TBL
$ DEFINE/NOLOG CUSP_S3_U_T3000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_U_T3000.TBL
$ DEFINE/NOLOG CUSP_S3_U_T5000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_U_T5000.TBL
$ DEFINE/NOLOG CUSP_S3_U_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S3_U_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S4_L_T550$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_L_T550.TBL
$ DEFINE/NOLOG CUSP_S4_L_T750$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_L_T750.TBL
$ DEFINE/NOLOG CUSP_S4_L_T2000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_L_T2000.TBL
$ DEFINE/NOLOG CUSP_S4_L_T4000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_L_T4000.TBL
$ DEFINE/NOLOG CUSP_S4_L_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_L_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S4_U_T550$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_U_T550.TBL
$ DEFINE/NOLOG CUSP_S4_U_T750$INP       'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_U_T750.TBL
$ DEFINE/NOLOG CUSP_S4_U_T2000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_U_T2000.TBL
$ DEFINE/NOLOG CUSP_S4_U_T4000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_U_T4000.TBL
$ DEFINE/NOLOG CUSP_S4_U_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S4_U_T10000.TBL
$! ---
$ DEFINE/NOLOG CUSP_S5_L_T1200$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_L_T1200.TBL
$ DEFINE/NOLOG CUSP_S5_L_T1400$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_L_T1400.TBL
$ DEFINE/NOLOG CUSP_S5_L_T3000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_L_T3000.TBL
$ DEFINE/NOLOG CUSP_S5_L_T5000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_L_T5000.TBL
$ DEFINE/NOLOG CUSP_S5_L_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_L_T10000.TBL
$ ---
$ DEFINE/NOLOG CUSP_S5_U_T1200$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_U_T1200.TBL
$ DEFINE/NOLOG CUSP_S5_U_T1400$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_U_T1400.TBL
$ DEFINE/NOLOG CUSP_S5_U_T3000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_U_T3000.TBL
$ DEFINE/NOLOG CUSP_S5_U_T5000$INP      'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_U_T5000.TBL
$ DEFINE/NOLOG CUSP_S5_U_T10000$INP     'TESTDIR2a'SUM_CUSP_C97_'REP'_S5_U_T10000.TBL
$! ---
$ DEFINE/NOLOG CCGF_SPALLING$OUT        'OUTDIR'SPALLING.TRN
$! ---
$! Define BLOWOUT file names
$! ---
$ DEFINE/NOLOG BF4_S1_L_T100$INP        'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T100.TBL
$ DEFINE/NOLOG BF4_S1_L_T350$INP        'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T350.TBL
$ DEFINE/NOLOG BF4_S1_L_T1000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T1000.TBL
$ DEFINE/NOLOG BF4_S1_L_T3000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T3000.TBL
$ DEFINE/NOLOG BF4_S1_L_T5000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T5000.TBL
$ DEFINE/NOLOG BF4_S1_L_T10000$INP      'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Lower_T10000.TBL
$! ---
$ DEFINE/NOLOG BF4_S1_U_T100$INP        'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T100.TBL
$ DEFINE/NOLOG BF4_S1_U_T350$INP        'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T350.TBL
$ DEFINE/NOLOG BF4_S1_U_T1000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T1000.TBL
$ DEFINE/NOLOG BF4_S1_U_T3000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T3000.TBL
$ DEFINE/NOLOG BF4_S1_U_T5000$INP       'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T5000.TBL
$ DEFINE/NOLOG BF4_S1_U_T10000$INP      'TESTDIR3a'SUM_dbr_C97_'REP'_S1_Up_T10000.TBL
$ ---
$ DEFINE/NOLOG BF4_S2_L_T550$INP        'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T550.TBL
$ DEFINE/NOLOG BF4_S2_L_T750$INP        'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T750.TBL
$ DEFINE/NOLOG BF4_S2_L_T2000$INP       'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T2000.TBL
```

```
$ DEFINE/NOLOG BF4_S2_L_T4000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T4000.TBL
$ DEFINE/NOLOG BF4_S2_L_T10000$INP            'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S2_U_T550$INP              'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_U_T550.TBL
$ DEFINE/NOLOG BF4_S2_U_T750$INP              'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T750.TBL
$ DEFINE/NOLOG BF4_S2_U_T2000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_U_T2000.TBL
$ DEFINE/NOLOG BF4_S2_U_T4000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_L_T4000.TBL
$ DEFINE/NOLOG BF4_S2_U_T10000$INP            'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S2_U_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S3_L_T1200$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_L_T1200.TBL
$ DEFINE/NOLOG BF4_S3_L_T1400$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_L_T1400.TBL
$ DEFINE/NOLOG BF4_S3_L_T3000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_L_T3000.TBL
$ DEFINE/NOLOG BF4_S3_L_T5000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_L_T5000.TBL
$ DEFINE/NOLOG BF4_S3_L_T10000$INP            'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_L_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S3_U_T1200$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_U_T1200.TBL
$ DEFINE/NOLOG BF4_S3_U_T1400$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_U_T1400.TBL
$ DEFINE/NOLOG BF4_S3_U_T3000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_U_T3000.TBL
$ DEFINE/NOLOG BF4_S3_U_T5000$INP             'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_U_T5000.TBL
$ DEFINE/NOLOG BF4_S3_U_T10000$INP            'TESTDIR8'SUM_bf4_ccgf_air_'REP'_S3_U_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S4_L_T550$INP              'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Lower_T550.TBL
$ DEFINE/NOLOG BF4_S4_L_T750$INP              'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Lower_T750.TBL
$ DEFINE/NOLOG BF4_S4_L_T2000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Lower_T2000.TBL
$ DEFINE/NOLOG BF4_S4_L_T4000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Lower_T4000.TBL
$ DEFINE/NOLOG BF4_S4_L_T10000$INP            'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Lower_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S4_U_T550$INP              'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Up_T550.TBL
$ DEFINE/NOLOG BF4_S4_U_T750$INP              'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Up_T750.TBL
$ DEFINE/NOLOG BF4_S4_U_T2000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Up_T2000.TBL
$ DEFINE/NOLOG BF4_S4_U_T4000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Up_T4000.TBL
$ DEFINE/NOLOG BF4_S4_U_T10000$INP            'TESTDIR3a'SUM_dbr_C97_'REP'_S4_Up_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S5_L_T1200$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Lower_T1200.TBL
$ DEFINE/NOLOG BF4_S5_L_T1400$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Lower_T1400.TBL
$ DEFINE/NOLOG BF4_S5_L_T3000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Lower_T3000.TBL
$ DEFINE/NOLOG BF4_S5_L_T5000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Lower_T5000.TBL
$ DEFINE/NOLOG BF4_S5_L_T10000$INP            'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Lower_T10000.TBL
$! ----
$ DEFINE/NOLOG BF4_S5_U_T1200$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Up_T1200.TBL
$ DEFINE/NOLOG BF4_S5_U_T1400$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Up_T1400.TBL
$ DEFINE/NOLOG BF4_S5_U_T3000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Up_T3000.TBL
$ DEFINE/NOLOG BF4_S5_U_T5000$INP             'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Up_T5000.TBL
$ DEFINE/NOLOG BF4_S5_U_T10000$INP            'TESTDIR3a'SUM_dbr_C97_'REP'_S5_Up_T10000.TBL
$! ----
$ DEFINE/NOLOG CCGF_BLOWOUT$OUT               'OUTDIR'BLOWOUT.TRN
$! ----
$! Define NUTS file names
$! ----
$ DEFINE/NOLOG ALG_ST_CCGF_CCA_S1$INP         'TESTDIR0'SUM_ST_CCGF_aeg1_'REP'_S1.TBL
$ DEFINE/NOLOG ALG_ST_CCGF_CCA_S2$INP         'TESTDIR0'SUM_ST_CCGF_aeg1_'REP'_S2.TBL
$! ----
$ DEFINE/NOLOG SUM_NUTS_S1$INP                'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S1.TBL
$! ----
$ DEFINE/NOLOG SUM_NUTS_S2_100$INP            'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S2_T100.TBL
$ DEFINE/NOLOG SUM_NUTS_S2_350$INP            'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S2_T350.TBL
$ DEFINE/NOLOG SUM_NUTS_S3_1000$INP           'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S3_T1000.TBL
$ DEFINE/NOLOG SUM_NUTS_S3_3000$INP           'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S3_T3000.TBL
$ DEFINE/NOLOG SUM_NUTS_S3_5000$INP           'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S3_T5000.TBL
$ DEFINE/NOLOG SUM_NUTS_S3_7000$INP           'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S3_T7000.TBL
$ DEFINE/NOLOG SUM_NUTS_S3_9000$INP           'TESTDIR4'SUM_NUT_CCGF_cca_'REP'_S3_T9000.TBL
$! ----
$ DEFINE/NOLOG SUM_NUTS_S4_100$INP            'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S4_T100.TBL
$ DEFINE/NOLOG SUM_NUTS_S4_350$INP            'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S4_T350.TBL
$ DEFINE/NOLOG SUM_NUTS_S5_1000$INP           'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S5_T1000.TBL
$ DEFINE/NOLOG SUM_NUTS_S5_3000$INP           'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S5_T3000.TBL
$ DEFINE/NOLOG SUM_NUTS_S5_5000$INP           'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S5_T5000.TBL
```

```
$! DEFINE/NOLOG SUM_NUTS_S6_7000$INP          'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S6_T7000.TBL
$! DEFINE/NOLOG SUM_NUTS_S6_9000$INP          'TESTDIR4'SUM_NUT_CCGF_CCA_'REP'_S6_T9000.TBL
$! ---
$ DEFINE/NOLOG SUM_PNL_S6_100$INP             'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_100.TBL
$ DEFINE/NOLOG SUM_PNL_S6_350$INP             'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_350.TBL
$ DEFINE/NOLOG SUM_PNL_S6_1000$INP            'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_1000.TBL
$ DEFINE/NOLOG SUM_PNL_S6_4000$INP            'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_4000.TBL
$ DEFINE/NOLOG SUM_PNL_S6_6000$INP            'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_6000.TBL
$ DEFINE/NOLOG SUM_PNL_S6_9000$INP            'TESTDIR6a'SUM_PANEL_CCDf_eeg1_'REP'_S6_9000.TBL
$! DEFINE/NOLOG SUM_PNL_S6_100$INP            'TESTDIR4'SUM_PANEL_CCDfgf_'REP'_S6_100.TBL
$! DEFINE/NOLOG SUM_PNL_S6_350$INP            'TESTDIR4'SUM_PANEL_CCDFgf_'REP'_S6_350.TBL
$! DEFINE/NOLOG SUM_PNL_S6_1000$INP           'TESTDIR4'SUM_PANEL_CCDFgf_'REP'_S6_1000.TBL
$! DEFINE/NOLOG SUM_PNL_S6_2000$INP           'TESTDIR4'SUM_PANEL_CCDFGF_'REP'_S6_2000.TBL
$! DEFINE/NOLOG SUM_PNL_S6_4000$INP           'TESTDIR4'SUM_PANEL_CCDFgf_'REP'_S6_4000.TBL
$! DEFINE/NOLOG SUM_PNL_S6_6000$INP           'TESTDIR4'SUM_PANEL_CCDFgf_'REP'_S6_6000.TBL
$! DEFINE/NOLOG SUM_PNL_S6_9000$INP           'TESTDIR4'SUM_PANEL_CCDFgf_'REP'_S6_9000.TBL
$! ---
$ DEFINE/NOLOG SUM_CCDFGF_CCA_CAVGE0D$INP  'TESTDIR5'SUM_PANEL_eeg1_CON_'REP'_S1.tbl
$ DEFINE/NOLOG SUM_CCDFGF_CCA_CAVGE1D$INP  'TESTDIR5'SUM_PANEL_eeg1_CON_'REP'_S2.tbl
$! ---
$ DEFINE/NOLOG CCGF_NUTS$OUT                  'OUTDIR'NUTS.TRN
$! ---
$! Define SECOTP file names
$! ---
$ DEFINE/NOLOG ST2D3_CCA_PM$INP               'TESTDIR2a'SUM_ST2D3_c97_R1_PM.TBL
$ DEFINE/NOLOG ST2D3_CCA_FM$INP               'TESTDIR2a'SUM_ST2D3_c97_R1_FM.TBL
$ DEFINE/NOLOG CCGF_SECOTP$OUT                'OUTDIR'SECOTP.TRN
$! ---
$ DEFINE/NOLOG CCGF_MISC$INP                  'TESTDIR1'CCGF_MISC_PRE_CCA.INP
$ DEFINE/NOLOG CCGF_SDB$INP                   'TESTDIR1'CCDFGF.SDB
$ DEFINE/NOLOG CCGF_PRT$OUT                   'OUTDIR'CCGF_CCDFGF_CCA_'REP'.OUT
$ DEFINE/NOLOG CCGF$OUT                       'OUTDIR'CCGF_cca_'REP'.OUT
$! ---
$! Define release summary tables file name
$! ---
$ DEFINE/NOLOG CCGF_RELTAB$OUT                'OUTDIR'ccgf_reltab_eeg1_'REP'.DAT
$! ---
$! Execute CCDFGF with preprocessor option
$! ---
$ CCDFGF
$! ---
$ EXIT
$! ---
```

Attachment 2: ALGEBRA file for Air Drilling Scenario

```
!---------------------------------------------------------------------------
!
!TITLE:BRAGFLO 1996 CCA CALCULATIONS: REPOSITORY SCALE BLOWOUT
!ANAYLST: Dan Stoelzel, SNL
!CREATED: NOV 2, 1995
!PURPOSE: ALGEBRA file computes properties that can not be obtained
!        from CAMDAT and/or assigns properties to element blocks.
!              THIS FILE PREPARES A CDB FILE FOR PREBRAG TO READ
!IMPORTANT: This file originates from J.E. Bean's algebra file for his FEP
!          model. The methodologies to calculate dip were copied from his
!          file with minor changes
!          made to account for the differences in the meshes.
!          ALGEBRA TO CALC. DIP IN REPOSITORY - SCALE BLOWOUT MODEL.
!          new version of bragflo
!
!            MODIFIED:
!                        MARCH 26, 1996
!                        BLOWOUT MODEL STRUGGLING IN PANEL SEAL REGION. TURNED OFF
!                        CAP PRESSURE IN PANEL SEAL AND HALITE BY SETTING EQUAL TO
!                        CAP PRESSURE IN WASTE REGION
!
!                        MAY 17, 1996
!                        ADDED BOUNDARY CONDITION WELL CALCULATION FOR E1-E2 SCEN
!                        NEW CHANGES FOR LATEST CCA ANALYSIS
!
!                        MAY 20, 1996
!                        WELL 2 INPUT FILE TO ACCOUNT FOR E1-E2 SAME PANEL BOUNDARY
!                        COND.
!
!                        MAY 30,1996
!                        ADDED LOGIC TO ACCOUNT FOR CHANGES IN ABANDONED WELLBORE PERM
!                        FOR BOUNDARY CONDITION WELL.
!                        SCENARIO 2 AND 4 FILE FIRST INTRUSION AT 350 YEARS
!
!                       December 1, 1997
!                       Changed Cutoff for pressure in the repository to allow Air Drilling
!                       Dale Rucker, EEG
!===========================================================================
!---------------------------------------------------------
!CHAPTER 0:  DEFINE NEW VARIABLE NAMES AND SOME NEEDED CONSTANTS
!---------------------------------------------------------
!===========================================================================
!
!
! SET CONSTANTS AND PUT IN WASTE REGION
LIMIT BLOCK 1
THETA1  = MAKEPROP(DIP_DEG[B:8]*2.0*PI[B:8]/360.0)
THETA2  = MAKEPROP(0.0)
!
!
PERM_X   = 10**PRMX_LOG
PERM_Y   = 10**PRMY_LOG
PERM_Z   = 10**PRMZ_LOG
SB_MIN   = SAT_RBRN * 1.05
POR_COMP = COMP_RCK/POROSITY
! CALCULATE PROPERTIES FOR DRZ & HALITE
LIMIT BLOCK 2 3
PERM_X   = 10**PRMX_LOG
PERM_Y   = 10**PRMY_LOG
PERM_Z   = 10**PRMZ_LOG
SB_MIN   = SAT_RBRN * 1.05
! NOW ADJUST POROSITY AND PORE COMPRESSIBILITY TO EQ. PORE VOL WITH CRUSHED
! ROOM HEIGHT
POROSITY = HEIGHT * POROSITY / HEIGHT[ID:1]
POR_COMP = COMP_RCK/POROSITY
! CAP PRESSURE MODEL CHANGES HERE:
```

```
CAP_MOD = CAP_MOD[ID:1]
PCT_A   = PCT_A[ID:1]
PCT_EXP = PCT_EXP[ID:1]
! CALC PROPERTIES FOR PANEL SEALS
LIMIT BLOCK 4
PERM_X  = 10**PRMX_LOG
PERM_Y  = 10**PRMY_LOG
PERM_Z  = 10**PRMZ_LOG
SB_MIN  = SAT_RBRN * 1.05
! NOW ADJUST POROSITY AND PORE COMPRESSIBILITY TO EQ. PORE VOL WITH CRUSHED
! ROOM HEIGHT
POROSITY = HEIGHT * POROSITY / HEIGHT[ID:1]
POR_COMP = COMP_RCK/POROSITY
! CAP PRESSURE MODEL CHANGES HERE:
CAP_MOD = CAP_MOD[ID:1]
PCT_A   = PCT_A[ID:1]
PCT_EXP = PCT_EXP[ID:1]
!===================================================================
[redacted]
!===================================================================
! SET WELLBORE PROPS
LIMIT BLOCK 7
SEBRINE1 = MAKEPROP(0.0)
SEGAS1   = MAKEPROP(0.0)
KRW1     = MAKEPROP(0.0)
KRG1     = MAKEPROP(0.0)
SEBRINE2 = MAKEPROP(0.0)
SEGAS2   = MAKEPROP(0.0)
KRW2     = MAKEPROP(0.0)
KRG2     = MAKEPROP(0.0)
SEBRINE3 = MAKEPROP(0.0)
SEGAS3   = MAKEPROP(0.0)
KRW3     = MAKEPROP(0.0)
KRG3     = MAKEPROP(0.0)
SEBRINE4 = MAKEPROP(0.0)
SEGAS4   = MAKEPROP(0.0)
KRW4     = MAKEPROP(0.0)
KRG4     = MAKEPROP(0.0)
! DEFINE CONSTANTS FOR THE THREE EQUATIONS TO BE USED TO CALCULATE FBHP
! EQUATION 1: (FOR BRINE FLOW ONLY, KRG = 0)
! FBHP = (A+BX+CY)/(1+DX+EY)
!    X = LOG10(BRINE CONST) LOG M^3/μA-S
!    Y = PANEL PRESSURE (Pa)
! 8,022,373 Pa < FBHP < 8,036,090 Pa
EQ1_A  = MAKEPROP(8002577.4)
EQ1_B  = MAKEPROP(621375.75)
EQ1_C  = MAKEPROP(0.024916098)
EQ1_D  = MAKEPROP(0.10254807)
EQ1_E  = MAKEPROP(5.1235777E-9)
! EQUATION 2: (FOR LOG10(KRG/KRW) < 0  BRINE DOMINATED FLOW)
! FBHP = (A+BX+CX^2+DX^3+EY)/(1+FX+GX^2+HY)
!    X = LOG10(KRG/KRB)
!    Y = PANEL PRESSURE (Pa)
! 225,453 Pa < FBHP < 8,028,643 Pa
EQ2_A  = MAKEPROP(947082.65)
EQ2_B  = MAKEPROP(2788147.8)
EQ2_C  = MAKEPROP(3451058.3)
EQ2_D  = MAKEPROP(-54884.388)
EQ2_E  = MAKEPROP(-0.017079483)
EQ2_F  = MAKEPROP(0.8953587)
EQ2_G  = MAKEPROP(0.54041537)
EQ2_H  = MAKEPROP(-4.9369107E-9)
! EQUATION 3: (FOR LOG10(KRG/KRW) > 0  GAS DOMINATED FLOW)
! FBHP = EXP(A+BX+CX^0.5+DE^-X+EY^0.5)
!    X = LOG10(KRG/KRB)
!    Y = PANEL PRESSURE (Pa)
```

```
! 153,271 Pa < FBHP < 385,493 pA
EQ3_A = MAKEPROP(6.9214335)
EQ3_B = MAKEPROP(-0.2274279)
EQ3_C = MAKEPROP(1.3680586)
EQ3_D = MAKEPROP(1.8350385)
EQ3_E = MAKEPROP(0.00045726223)
!
! CALCULATE SKIN FROM SPALL REMOVED, & WELL PRODUCTIVITY INDEX
! ELEMENT 59 IS LOCATION OF WELL 2 (2ND INTRUSION DOWN DIP)
WELLRAD = BITSIZE/2
DRAINRAD = SQRT(DEL_X[E:59]*DEL_Y[E:59]/PI[B:8])
SKIN    = -1.0*LOG(SQRT(AREA_TOT/PI[B:8])/WELLRAD)
SKIN    = IFLT0(SKIN,SKIN,0)
! CHECK TO BE SURE WELLPI IS NOT 0 OR NEG. & SET TO 1.0 IF IT IS
! WELLPI  = PERM_X[ID:1] * HEIGHT[ID:1] / (LOG(DRAINRAD/WELLRAD) + SKIN - 0.5)
WELLPI  = IFGT0(LOG(DRAINRAD/WELLRAD) + SKIN - 0.5,PERM_X[ID:1]*HEIGHT[ID:1] &
          / (LOG(DRAINRAD/WELLRAD) + SKIN - 0.5),1.0)
! CALCULATE CONSTANTS NEEDED FOR WELLBORE MODEL
! CALCULATE EFFECTIVE SATURATION USING KRP = 4 (BROOKS - COREY MODIFIED,
! WITH LAMBDA (PORE_DIS) = 2.89, NO CAP PRESSURE). DO FOR 4 COUPLED REGIONS
! REGION NO 1 (PANELS 1 & 6)
BRINE1   = IFLT0((BSATPAN1[ID:1]-SAT_RBRN[ID:1]),SAT_RBRN[ID:1],BSATPAN1[ID:1])
SEBRINE1 = (BRINE1 - SAT_RBRN[ID:1])/(1.0 - SAT_RBRN[ID:1])
SEGAS1   = (BRINE1 - SAT_RBRN[ID:1])/(1.0-SAT_RBRN[ID:1]-SAT_RGAS[ID:1])
SEGAS1   = IFLT0((1.0 - SEGAS1),1.0,SEGAS1)
KRW1     = SEBRINE1**((2+3*PORE_DIS[ID:1])/PORE_DIS[ID:1])
KRG1     = (1.0-SEGAS1)**2*(1.0-SEGAS1**((2 + PORE_DIS[ID:1])/PORE_DIS[ID:1]))
! NOW CALCULATE CONSTANT FOR BRINE AND GAS
CONBR1   = WELLPI * KRW1 / VISCO[ID:5]
CONGAS1  = WELLPI * KRG1 / VISCO[ID:6]
! NOW TAKE LOG BASE 10 OF PARAMETERS NEEDED FOR FBHP EQUATIONS
LOG_B1   = IFEQ0(KRW1,-10,LOG10(CONBR1+1E-24))
LOG_KR1  = IFEQ0(KRW1,10,LOG10((KRG1+1E-24)/(KRW1+1E-24)))
! CALCULATE FBHP's AND SET WITHIN LIMITS
PR1_EQ1 = (EQ1_A+EQ1_B*LOG_B1+EQ1_C*PRESPAN1[ID:1])/ &
        (1.0+EQ1_D*LOG_B1+EQ1_E*PRESPAN1[ID:1])
PR1_EQ1 = IFLT0(8002373.0 - PR1_EQ1,IFLT0(8036090.0 - PR1_EQ1,8036090.0, &
        PR1_EQ1),8002373.0)
PR1_EQ2 = (EQ2_A+EQ2_B*LOG_KR1+EQ2_C*LOG_KR1**2+EQ2_D*LOG_KR1**3+ &
        EQ2_E*PRESPAN1[ID:1])/(1.0+EQ2_F*LOG_KR1+EQ2_G*LOG_KR1**2+ &
        EQ2_H*PRESPAN1[ID:1])
PR1_EQ2 = IFLT0(225453.0 - PR1_EQ2,IFLT0(8028643.0 - PR1_EQ2,8028643.0, &
        PR1_EQ2),225453.0)
PR1_EQ3 = EXP(EQ3_A+EQ3_B*LOG_KR1+EQ3_C*ABS(LOG_KR1)**0.5+ &
        EQ3_D*EXP(-1.0*ABS(LOG_KR1))+EQ3_E*PRESPAN1[ID:1]**0.5)
PR1_EQ3 = IFLT0(153271.0 - PR1_EQ3,IFLT0(385493.0 - PR1_EQ3,385493.0, &
        PR1_EQ3),153271.0)
! RESET FBHP TO 0 IF NO BRINE BLOWOUT (KRW = 0 OR PRESSURE < 2 MPa (300 psi))
[redacted]
! IF NO BLOWOUT, SET NUMBER OF BRAGFLO STEPS TO 1, ELSE 1000
NUMSTEP1 = MAKEPROP(IFEQ0(FBHP1,1,1000))
! REGION NO 2 (PANELS 2 &7)
BRINE2   = IFLT0((BSATPAN2[ID:1]-SAT_RBRN[ID:1]),SAT_RBRN[ID:1],BSATPAN2[ID:1])
SEBRINE2 = (BRINE2 - SAT_RBRN[ID:1])/(1.0 - SAT_RBRN[ID:1])
SEGAS2   = (BRINE2 - SAT_RBRN[ID:1])/(1.0-SAT_RBRN[ID:1]-SAT_RGAS[ID:1])
SEGAS2   = IFLT0((1.0 - SEGAS2),1.0,SEGAS2)
KRW2     = SEBRINE2**((2+3*PORE_DIS[ID:1])/PORE_DIS[ID:1])
KRG2     = (1.0-SEGAS2)**2*(1.0-SEGAS2**((2 + PORE_DIS[ID:1])/PORE_DIS[ID:1]))
! NOW CALCULATE CONSTANT FOR BRINE AND GAS
CONBR2   = WELLPI * KRW2 / VISCO[ID:5]
CONGAS2  = WELLPI * KRG2 / VISCO[ID:6]
! NOW TAKE LOG BASE 10 OF PARAMETERS NEEDED FOR FBHP EQUATIONS
LOG_B2   = IFEQ0(KRW2,-10,LOG10(CONBR2+1E-24))
LOG_KR2  = IFEQ0(KRW2,10,LOG10((KRG2+1E-24)/(KRW2+1E-24)))
! CALCULATE FBHP's AND SET WITHIN LIMITS
PR2_EQ1 = (EQ1_A+EQ1_B*LOG_B2+EQ1_C*PRESPAN2[ID:1])/ &
        (1.0+EQ1_D*LOG_B2+EQ1_E*PRESPAN2[ID:1])
PR2_EQ1 = IFLT0(8002373.0 - PR2_EQ1,IFLT0(8036090.0 - PR2_EQ1,8036090.0, &
```

```
        PR2_EQ1),8002373.0)
PR2_EQ2  = (EQ2_A+EQ2_B*LOG_KR2+EQ2_C*LOG_KR2**2+EQ2_D*LOG_KR2**3+ &
        EQ2_E*PRESPAN2[ID:1])/(1.0+EQ2_F*LOG_KR2+EQ2_G*LOG_KR2**2+ &
        EQ2_H*PRESPAN2[ID:1])
PR2_EQ2  = IFLT0(225453.0 - PR2_EQ2,IFLT0(8028643.0 - PR2_EQ2,8028643.0, &
        PR2_EQ2),225453.0)
PR2_EQ3  = EXP(EQ3_A+EQ3_B*LOG_KR2+EQ3_C*ABS(LOG_KR2)**0.5+ &
        EQ3_D*EXP(-1.0*ABS(LOG_KR2))+EQ3_E*PRESPAN2[ID:1]**0.5)
PR2_EQ3  = IFLT0(153271.0 - PR2_EQ3,IFLT0(385493.0 - PR2_EQ3,385493.0, &
        PR2_EQ3),153271.0)
! RESET FBHP TO 0 IF NO BRINE BLOWOUT (KRW = 0 OR PRESSURE < 2 MPa)
[redacted]
! IF NO BLOWOUT, SET NUMBER OF BRAGFLO STEPS TO 1, ELSE 1000
NUMSTEP2 = MAKEPROP(IFEQ0(FBHP2,1,1000))
! REGION NO 3 (PANELS 3 & 6)
BRINE3   = IFLT0(BSATPAN3[ID:1]-SAT_RBRN[ID:1],SAT_RBRN[ID:1],BSATPAN3[ID:1])
SEBRINE3 = (BRINE3 - SAT_RBRN[ID:1])/(1.0 - SAT_RBRN[ID:1])
SEGAS3   = (BRINE3 - SAT_RBRN[ID:1])/(1.0-SAT_RBRN[ID:1]-SAT_RGAS[ID:1])
SEGAS3   = IFLT0(1.0 - SEGAS3),1.0,SEGAS3)
KRW3     = SEBRINE3**((2+3*PORE_DIS[ID:1])/PORE_DIS[ID:1])
KRG3     = (1.0-SEGAS3)**2*(1.0-SEGAS3**((2 + PORE_DIS[ID:1])/PORE_DIS[ID:1]))
! NOW CALCULATE CONSTANT FOR BRINE AND GAS
CONBR3   = WELLPI * KRW3 / VISCO[ID:5]
CONGAS3  = WELLPI * KRG3 / VISCO[ID:6]
! NOW TAKE LOG BASE 10 OF PARAMETERS NEEDED FOR FBHP EQUATIONS
LOG_B3   = IFEQ0(KRW3,-10,LOG10(CONBR3+1E-24))
LOG_KR3  = IFEQ0(KRW3,10,LOG10((KRG3+1E-24)/(KRW3+1E-24)))
! CALCULATE FBHP's AND SET WITHIN LIMITS
PR3_EQ1  = (EQ1_A+EQ1_B*LOG_B3+EQ1_C*PRESPAN3[ID:1])/ &
        (1.0+EQ1_D*LOG_B3+EQ1_E*PRESPAN3[ID:1])
PR3_EQ1  = IFLT0(8002373.0 - PR3_EQ1,IFLT0(8036090.0 - PR3_EQ1,8036090.0, &
        PR3_EQ1),8002373.0)
PR3_EQ2  = (EQ2_A+EQ2_B*LOG_KR3+EQ2_C*LOG_KR3**2+EQ2_D*LOG_KR3**3+ &
        EQ2_E*PRESPAN3[ID:1])/(1.0+EQ2_F*LOG_KR3+EQ2_G*LOG_KR3**2+ &
        EQ2_H*PRESPAN3[ID:1])
PR3_EQ2  = IFLT0(225453.0 - PR3_EQ2,IFLT0(8028643.0 - PR3_EQ2,8028643.0, &
        PR3_EQ2),225453.0)
PR3_EQ3  = EXP(EQ3_A+EQ3_B*LOG_KR3+EQ3_C*ABS(LOG_KR3)**0.5+ &
        EQ3_D*EXP(-1.0*ABS(LOG_KR3))+EQ3_E*PRESPAN3[ID:1]**0.5)
PR3_EQ3  = IFLT0(153271.0 - PR3_EQ3,IFLT0(385493.0 - PR3_EQ3,385493.0, &
        PR3_EQ3),153271.0)
! RESET FBHP TO 0 IF NO BRINE BLOWOUT (KRW = 0 OR PRESSURE < 2 MPa)
[redacted]
! IF NO BLOWOUT, SET NUMBER OF BRAGFLO STEPS TO 1, ELSE 1000
NUMSTEP3 = MAKEPROP(IFEQ0(FBHP3,1,1000))
! REGION NO 4 (PANELS 4 & 5)
BRINE4   = IFLT0(BSATPAN4[ID:1]-SAT_RBRN[ID:1],SAT_RBRN[ID:1],BSATPAN4[ID:1])
SEBRINE4 = (BRINE4 - SAT_RBRN[ID:1])/(1.0 - SAT_RBRN[ID:1])
SEGAS4   = (BRINE4 - SAT_RBRN[ID:1])/(1.0-SAT_RBRN[ID:1]-SAT_RGAS[ID:1])
SEGAS4   = IFLT0(1.0 - SEGAS4),1.0,SEGAS4)
KRW4     = SEBRINE4**((2+3*PORE_DIS[ID:1])/PORE_DIS[ID:1])
KRG4     = (1.0-SEGAS4)**2*(1.0-SEGAS4**((2 + PORE_DIS[ID:1])/PORE_DIS[ID:1]))
! NOW CALCULATE CONSTANT FOR BRINE AND GAS
CONBR4   = WELLPI * KRW4 / VISCO[ID:5]
CONGAS4  = WELLPI * KRG4 / VISCO[ID:6]
! NOW TAKE LOG BASE 10 OF PARAMETERS NEEDED FOR FBHP EQUATIONS
LOG_B4   = IFEQ0(KRW4,-10,LOG10(CONBR4+1E-24))
LOG_KR4  = IFEQ0(KRW4,10,LOG10((KRG4+1E-24)/(KRW4+1E-24)))
! CALCULATE FBHP's AND SET WITHIN LIMITS
PR4_EQ1  = (EQ1_A+EQ1_B*LOG_B4+EQ1_C*PRESPAN4[ID:1])/ &
        (1.0+EQ1_D*LOG_B4+EQ1_E*PRESPAN4[ID:1])
PR4_EQ1  = IFLT0(8002373.0 - PR4_EQ1,IFLT0(8036090.0 - PR4_EQ1,8036090.0, &
        PR4_EQ1),8002373.0)
PR4_EQ2  = (EQ2_A+EQ2_B*LOG_KR4+EQ2_C*LOG_KR4**2+EQ2_D*LOG_KR4**3+ &
        EQ2_E*PRESPAN4[ID:1])/(1.0+EQ2_F*LOG_KR4+EQ2_G*LOG_KR4**2+ &
        EQ2_H*PRESPAN4[ID:1])
PR4_EQ2  = IFLT0(225453.0 - PR4_EQ2,IFLT0(8028643.0 - PR4_EQ2,8028643.0, &
```

```
        PR4_EQ2),226483.0)
 PR4_EQ3 = EXP(EQ3_A+EQ3_B*LOG_KR4+EQ3_C*ABS(LOG_KR4)**0.5+ &
        EQ3_D*EXP(-1.0*ABS(LOG_KR4))-EQ3_E*PRESPAN4[ID:*]**0.5)
 PR4_EQ3 = IFLT0(153271.0 - PR4_EQ3,IFLT0(385493.0 - PR4_EQ3,385493.0, &
        PR4_EQ3),153271.0)
 ! RESET FBHP TO 0 IF NO BRINE BLOWOUT (KRW = 0 OR PRESSURE < 2 MPa)
[redacted]
 ! IF NO BLOWOUT, SET NUMBER OF BRAGFLO STEPS TO 1, ELSE 1000
 NUMSTEP4 = MAKEPROP(IFEQ0(FBHP4,1,1000))
 DELETE BRINE1, BRINE2, BRINE3, BRINE4
 !=====================================================================
 !---------------------------------------------------------------
 !SET UP BOUNDARY CONDITIONS FOR PREVIOUS INTRUSIONS HERE
 !---------------------------------------------------------------
 ! SET UP NEEDED CONSTANTS (NOTE: BOREHOLE LENGTH FROM PANEL TO CASTILE B.P.
 ! IS 247 METERS -- USED IN CON_SAND & CON_CREP)
 ! MODIFICATIONS MADE 5/30/96
 LEN_BC   = MAKEPROP(247.0)
 DRAIN_BC = MAKEPROP(SQRT(DEL_X[E:15]*DEL_Y[E:15]/PI[3:8]))
 WELPI_BC = PERM_X[ID:1] * HEIGHT[ID:1] / (LOG(DRAIN_BC/WELLRAD) + 0.0 - 0.5)
 RHO_G_H  = MAKEPROP(DNSFLUID[ID:5]*GRAVACC[ID:8]*LEN_BC)
 CON_OPEN = MAKEPROP((PRM_CAST*THCK_CAS[ID:5]*(LOG(DRAIN_BC/WELLRAD)-0.5)) &
        / (PERM_X[ID:1]*HEIGHT[ID:1]*(LOG(RE_CAST[ID:5]/WELLRAD)-0.5)))
 CON_SAND = MAKEPROP((PRM_SAND*PI[ID:8]*WELLRAD*WELLRAD* &
        (LOG(DRAIN_BC/WELLRAD)-0.5)) / (PERM_X[ID:1]*HEIGHT[ID:1]*LEN_BC))
 CON_CREP = MAKEPROP((PRM_CREP*PI[ID:8]*WELLRAD*WELLRAD* &
        (LOG(DRAIN_BC/WELLRAD)-0.5)) / (PERM_X[ID:1]*HEIGHT[ID:1]*LEN_BC))
 ! SOLVE FOR OPEN BOREHOLE TO CASTILE B.C. (WITHIN 200 YEARS AFTER FIRST INTR.)
 ! USE FBHP4 SINCE BOUNDARY CONDITION WELL IS ASSUMED TO BE IN PANEL 5 (DOWN-
 ! DIP) FOR ALL SUBSEQUENT INTRUSIONS
 BHP_OPEN = (FBHP4+CON_OPEN*(CAST_RE-RHO_G_H))/(1.0+CON_OPEN)
 ! SOLVE FOR SAND-FILLED BH CONDITION (200 TO 1200 YEARS AFTER 1ST INTRUSION)
 BHP_SAND = (FBHP4+CON_SAND*(CAST_WB-RHO_G_H))/(1.0+CON_SAND)
 ! SOLVE FOR CREEP CLOSED BH CONDITION (> 200 YEARS AFTER 1ST INTRUSION)
 BHP_CREP = (FBHP4+CON_CREP*(CAST_WB-RHO_G_H))/(1.0+CON_CREP)
 !ASSIGN ABANDONED BH PRESSURE BASED ON INTRUSION TIME
 PREV_TME = MAKEPROP(1000.0)
 DELT_TME = INTR_TME/YRSEC[ID:8] - PREV_TME
 BHP_ABAN = IFGT0(DELT_TME - 200,1,IFGT0(DELT_TME - 1200,1,BHP_CREP,BHP_SAND), &
        BHP_OPEN)
 !---------------------------------------------------------------
 !===============================================================
 !=====================================================================
 !---------------------------------------------------------------
 !CHAPTER 3.  COMPUTE DIP IN REPOSITORY
 !---------------------------------------------------------------
 !---------------------------------------------------------------
 !---------------------------------------------------------------
 !===============================================================
 LIMIT ELEMENT OFF
 !COMPUTE THE GRID BLOCK ELEVATIONS ACCOUNTING FOR 1 DEGREE DIP IN SALADO
 !DEFINE GRID BLOCK ELEVATIONS DUE TO DIP
 ! USE ELEVATION OF SHAFT AT MID-REPOSITORY
 ZORIGIN  = 382.671
 YORIGIN  = 1000.0
 ELEVN    = MAKENODE(COS(THETA1[ID:1])*(Z-ZORIGIN) &
          - SIN(THETA1[ID:1])*(Y-YORIGIN))
 ELEVE    = NOD2ELE(ELEVN) + ZORIGIN
 !COMPUTE GRID BLOCK POTENTIAL ASSUMING BRINE IS INCOMPRESSIBLE (APPROXIMATELY)
 POTE     = PRESEL/(DNSFLUID[ID:5]*GRAVACC[ID:8]) + ELEVE
 !
 ! NOW SET GRID THICKNESS FOR ALL ELEMENTS TO CRUSHED PANEL HEIGHT
 THICK    = MAKEATTR(HEIGHT[ID:1])
 !
 DELETE ELEVN, YORIGIN, ZORIGIN
 EXIT
```

8.4a. Solubility of Plutonium as Expected Under Conditions in the WIPP Repository (V.M. Oversby, 1997)

THE SOLUBILITY OF PLUTONIUM UNDER CONDITIONS EXPECTED IN THE WIPP REPOSITORY

V. M. Oversby
VMO Konsult
Karlavägen 70
S-114 59 Stockholm
Sweden

October 31, 1997

This report was prepared for the Environmental Evaluation Group, Albuquerque, New Mexico. Every attempt has been made to make the report as complete as possible within the time available for its preparation; however, the author cannot guarantee that all relevant work is included in the discussion. The author is not responsible for the subsequent use of information and opinions contained in this report.

Table of Contents

Introduction

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico. It is designed to be a final disposal site for transuranic wastes (TRU) produced from defense-related activities in the USA. The repository site is 655 meter below ground surface in a bedded salt formation (Salado Fm.) of Permian age. The planned inventory of wastes includes 850,000 canisters of relatively low activity, contact-handled, TRU, and about 7500 canisters of higher activity, remote-handled, TRU (Chaturvedi et al., 1997). The remote handled TRU canisters will contain about 15% of the total activity in the repository and, thus, can be expected to contain the highest concentrations of Pu and Am, the main actinide constituents in the waste.

The Environmental Evaluation Group (EEG) conducts independent technical evaluations of the impact of the WIPP project on public health and on the environment. In October, 1996, the US Department of Energy submitted their Compliance Certification Application (CCA) to the US Environmental Protection Agency. During their independent review of the CCA, EEG identified a number of concerns (Chaturvedi et al., 1997). They determined that an additional review of the factors that influence the solubility of plutonium under the conditions that will pertain at WIPP would assist them in their evaluation of the CCA. The work covered by this report was initiated in response to EEG's request. Some specific questions were proposed as important to their evaluation:

Is there enough experimental evidence to rigorously conclude that plutonium will be in the Pu(III) and Pu(IV) states in the repository environment, rather than the potentially more soluble Pu(V) state?

Is there something that has not been considered in the CCA that might result in higher Pu solubility?

What is the effect on the solubility of Pu of the compounds formed by the MgO backfill interactions with brine?

What, specifically, are the scientific shortcomings of the DOE arguments in the CCA and what needs to be done to address these shortcomings in terms of calculations and experimental work?

This report attempts to answer those questions by discussing the most likely redox state for Pu based on published experimental work, the effect of brine composition on solubility of actinides in the (IV) valence state, the influence of solution species formed by reaction of the MgO backfill on An(IV) solubility, and the influence of other potential ligands present in the waste itself on actinide solubility. An analysis of the calculational path used as a result of the scenario adopted for the calculations suggests that there are means of forming significant amounts of soluble Pu as citrate complexes or as complexes with the chemical degradation products of cellulose. A new scenario for calculations to test the sensitivity of the results to pathway is proposed. In addition, some inconsistencies in the calculated results reported in the CCA are discussed and issues are identified that need resolution.

Factors controlling solubility

There are four major factors that will determine the effective solubility of plutonium in the WIPP environment. These are (1) the redox conditions, (2) the brine composition, (3) the availability of ligands through degradation of the waste, and (4) the effects of slow kinetics of reaction due to lack of lability of species (i.e., persistence of metastable species). The brine composition, itself, will be affected by the persistence of metastable reaction products, especially those formed by the MgO backfill. Each of these factors is discussed in the sections that follow.

Redox state

Plutonium can exist in several oxidation states in natural waters depending on the availabilty of oxygen and complexing agents. Under normal atmospheric carbon dioxide pressure (p_{CO_2}= 3.2 x10^{-4} atm), but in the absence of other complexing ligands, the expected oxidation states of Pu are PuO_2^{2+}, PuO_2^{+}, and Pu^{4+} under oxic conditions and Pu^{4+} and Pu^{3+} under reducing conditions. PuO_2^{+} disproportionates into PuO_2^{2+} and Pu^{4+}, but the rate of the reaction depends on the 4th power of the H^{+} concentration and on the square of the PuO_2^{+} concentration so that at low concentrations of Pu in neutral solutions the reaction rate is negligible (Choppin, 1990). This suggests that PuO_2^{+}, once present, may persist outside of its stability field because of slow reaction kinetics.

During the operational period of the WIPP repository, oxygen will be present in the storage rooms. This oxygen will be trapped in the salt formation after repository closure and will be available to react with the waste materials and their containers. Void space in the repository will be reduced by salt creep, and the encroaching salt will eventually crush the waste drums. The residual oxygen can react with the drum material or with the waste itself, producing soluble corrosion products, such as Fe^{2+}, and possibly PuO_2^{+}. Radiolysis of water inside the waste drums can also result in oxidation of plutonium to produce PuO_2^{+}. If there are organic complexing agents present, the PuO_2^{+} will be rapidly reduced to Pu(IV) and stabilized in solution as soluble complex ions (AlMahamid et al., 1996). It is reasonable to conclude that PuO_2^{+} will not be able to coexist with organic ligands for any significant period of time, and that solubility calculations should consider either transient presence of PuO_2^{+} or presence of Pu(IV) with or without organic ligands.

Weiner et al. (1996) discuss the possible oxidation states of Pu under WIPP conditions. They conclude that Pu(IV) is expected to be the stable state, but include Pu(III) based on observations by Felmy et al. (1989). These 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 up to pH 9 in modelling 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) is set by the detection limit in the Felmy et al. (1989) experiments as 10^{-9} M.

Pu(V) has been observed in a number of experiments conducted in brines. Weiner et al. (1996) discuss some of these results in Appendix A to their report and conclude that Pu(V) will not be important because it disappears with time. This conclusion would be perfectly valid for cases where release from the repository is assumed to occur through flow mechanisms that take long periods of time to reach the accessible environment; however, for human intrusion scenarios where the brine may reach the surface directly via a borehole, it is probably more valid to include transient species that have been shown to have long lifetimes. Since any Pu(V) is likely to react with dissolved Fe(II), the steady-state amount of Pu(V) should be small and not lead to a large increase in calculated total mobile Pu species in the repository.

Brine composition

Brine composition can affect solubility in two principal ways. The first is through the effect of ionic strength, which will generally lead to higher actinide solubilities for high ionic strength. Most of the effect of ionic strength increase is seen by the time a solution concentration of 2M NaCl is reached, with little change in effective activity coefficients expected as ionic strength increases further. The second means of affecting solubility is through the formation of complex ions. Carbonate ion and hydroxyl ion are the main inorganic ligands that will cause increased solubility of Pu in the WIPP brines. Novak and Moore (1996) calculated that sulfate complexes are important for some cases; see Appendix B for discussion.

In this section we will consider experimental evidence that can be used to evaluate the expected effects of brine composition on the solubility of Pu. The conclusions that can be drawn from the experimental evidence will be useful in assessing the validity of model calculations. Most measurements using Pu have been done with oxygen present in the system, either with normal atmospheric composition together with carbon dioxide, or under argon glove box conditions with 18 to 30 ppm oxygen in the gas. While the latter amount may seem very small, it is enough to provide for oxidation of Pu from Pu(IV) to Pu(V) in solution. Once Pu(V) is formed, it may be long-lived if there is not an active reductant present.

DePablo et al. (1995) conducted experiments using unirradiated crystalline UO_2 (s) in synthetic brines. Both oxidizing and reducing conditions were studied; reducing conditions were maintained using a hydrogen flux and a Pd catalyst. Carbon dioxide was not present in the experiments. Brine compositions (molal concentrations) were

Species	NaCl-brine	$MgCl_2$-brine
Na+	6.036	0.48
K+	0.037	0.57
Mg^{2+}	0.018	4.21
Ca^{2+}	0.021	0
Cl-	6.036	8.84
$SO_4^{=}$	0.058	0.32
Ionic Str.	6.25	14.00
pH	7.7	4.7

The UO_2 (s) had an initial surface condition that was very oxidized, $UO_{2.7}$ as measured by XPS. This led to an initial rapid dissolution of the oxidized surface even when the solution was maintained with reducing conditions. The solution concentrations in both brines gradually decreased and settled after 20 to 25 days at steady-state values of 2.8×10^{-7} mol/kg in the NaCl brine and 3.1×10^{-7} mol/kg in the $MgCl_2$-brine. At the end of the experiments the Eh was measured to be 0 to 60 mV (compatible with the stability of UO_2) and the surface of the dissolving solid was measured to have a composition of $UO_{2.1}$ as measured by XPS. A model calculation was done using the PHRQPITZ code (the PHREEQE equilibrium code with Pitzer parameters added) and gave quite good agreement of the concentrations predicted by the calculations with those measured in the experiments. The calculated concentrations for zero ionic strength solutions were about a factor of 3 lower than those calculated for the brines.

The experiments of DePablo et al. (1995) show that for UO_2 (s), there is very little variation in solubility that can be attributed to the combined effects of increasing the brine ionic strength by a factor of more than 2 and simultaneously increasing sulfate by a factor of 5. In addition, changing the dominant cation from Na+ to Mg^{2+} did not seem to have a large effect. From the modelling calculations, the effect of high ionic strength on solubility of the UO_2 (s) was limited to an increase of a factor of 3.

The effect of carbonate ion on the solubility of Th was measured in solubility and speciation experiments by Östhols et al. (1994). They measured the solubility of a freshly precipitated thorium oxide/hydroxide with low crystallinity as a function of pH with an atmosphere of 10% carbon dioxide. They analyzed the data and deduced speciation with $Th(OH)_3CO_3^-$ as the dominant species from pH 5 to slightly greater than 7 and with $Th(CO_3)_5^{6-}$ beginning to occur at pH just under 7 and taking over from the hydroxycarbonate complex after pH7.4. The total solubility of Th(IV) at pH 7 was 10^{-5} M. Östhols et al. (1994) also calculated stability constants for these species and the solubility product for amorphous ThO_2 for their experimental solution conditions of 0.5 M $NaClO_4$ and for the extrapolated values at zero ionic strength.

Rai et al. (1995) measured the solubility of U(IV) and Th(IV) freshly precipitated oxides under inert atmosphere conditions as a function of carbonate/bicarbonate concentration in solution. For the U experiments, Fe powder was added to the solutions to ensure that no U(VI) formed. At low carbonate concentration, the uranium solubility was about 10^{-8} M. (This is about a factor of 10 lower than the value calculated by DePablo et al. (1995) for low ionic strength and no carbonate. See above). Two data points at a carbonate content of 0.1 molal also had a solubility of 10^{-8} M for Th(IV). The Th solubility increased to be 10^{-5} M at a sodium carbonate content of about 0.3 m, which is similar to the carbonate content that one would expect with a partial pressure of CO_2 of 0.1 atmosphere. For U, a carbonate concentration about a factor of 4 higher was needed to achieve the same solubility of 10^{-5} M. It should be noted that for both U and Th, the concentration of carbonate had to exceed 0.1 molal before a dramatic increase in solubility was observed.

From the results presented above, we may derive two important conclusions concerning the effect of brine composition on Pu(IV) solubility.

(1) The detailed composition of the brine will probably not be important in determining Pu(IV) solubility in the absence of organic ligands and at low carbonate concentrations.

(2) Carbonate ion concentrations will only have a large effect on Pu(IV) solubility if they are above 0.1 molal.

These conclusions should be valuable in assessing the reliability of modelling calculations for WIPP long-term performance predictions.

Experimental studies of Th and Pu solubility were supported by the WIPP Project in FY 1997 to determine what the effects of the MgO backfill would be on solubility and to validate the model assumption that Th data could be used to model Pu behavior. Preliminary results are available in the annual report for

FY97 (Rai et al., 1997). All experiments were done with nitrogen atmosphere. The concentrations of Th in the presence of MgO after 5 days exposure in two brines was between $10^{-7.3}$ and 10^{-8} M, while with hydromagnesite present the solubility was much higher (10^{-5} and $10^{-6.5}$ M). The solubility of amorphous plutonium dioxide in the brines in the presence of Fe powder was measured to be $10^{-6.5}$ M at pH 7.5 and $10^{-7.5}$ M at pH 8. Solubility changes when hydromagnesite was present were +/- a factor of 10 with increase in pH of 0.5 units in both brines. The presence of $Na_2S_2O_4$, a strong reducing agent, resulted in higher Pu solubility in all cases. This was interpreted to indicate the possible presence of Pu(III) species that were more soluble than the Pu(IV) species. Pu(V) was also considered as a possible species to explain some of the higher-than-expected concentrations found.

The solubilities for Pu in the absence of carbonate found by Rai et al. (1997) are quite similar to those found by DePablo et al. (1995) for UO_2. Solubilities for Pu and Th depend to a large degree on the “age” of the solid and its degree of crystallinity. This factor is less important for UO_2. Since the preliminary results for Pu in brines seem to be consistent with those for UO_2 solubility in brines, the UO_2 solubility data measured in brines would seem to represent a sounder basis for performance prediction than those calculated from a model based on Th with Pitzer parameters. This conclusion is strengthened by the fact that the solubilities of Th measured by Rai et al. (1997) in the presence of hydromagnesite are much higher than those calculated by Novak (1997 - see discussion in the next section and in Appendix A).

Phases controlling brine composition

The brine compositions assumed for the WIPP performance assessment conditions are either the Salado brine or the Castile brine or a mixture of these brines. To assess the solubility of actinides in the brines, Novak and Moore (1996) further assumed that the brines became saturated with halite and anhydrite, the major minerals in the associated salt formations. The effective pH of the brines under these conditions was about 5.6 to 5.8, which was thought to be lower than desirable. Actinide solubility goes down with increasing pH, at least until pH of 11 or 12 is reached; for this reason, addition of a backfill material was considered to buffer the pH at about 10 and to absorb CO_2 gas that might be generated by microbial action. (See Appendix A for a more detailed discussion of this issue.)

The MgO from the backfill was thought to produce brucite and magnesite as its stable reaction products and that these materials would be those responsible for conditioning the brine chemistry. During experiments with alteration of MgO with the brines, it was found that other phases formed. These phases are (or, at least, may be) metastable with respect to magnesite and brucite; however, they may persist for extended periods of time under the WIPP disposal conditions. The draft report on the MgO alteration shows evidence for the formation of reaction products that are predominantly nesquehonite ($MgCO_3 \cdot 3H_2O$) with the later appearance of a phase that could not be positively identified, but was tentatively identified as $MgCO_3 \cdot 3H_2O \cdot MgCl(OH)$ (PDF7-278) (no name given). The chemistry of this phase is quite different from that of hydromagnesite [$(MgCO_3)_4 \cdot Mg(OH)_2 \cdot 4H_2O$]. Despite this, the draft report claims on page 30 that "we observed that hydromagnesite, with a loose platy habit, is the favored metastable phase in our experiments, rather than nesquehonite" (Sandia, 1997).

The identity of the Mg-carbonate phase that forms with alteration of MgO is important because this phase will control the carbonate and bicarbonate concentrations in the brines. High concentrations of carbonate in the brines can increase the solubility of Pu via complex ion formation with carbonate. Calculations in the Sandia, 1997, draft manuscript reported only the effect of hydromagnesite on expected actinide solubility. Hydromagnesite, however, was never identified in the experiments described in the draft manuscript. In other materials available from Sandia, it was seen that calculations were also done with nesquehonite (C. F. Novak memo to R. Vann Bynum dated 21 April 1997, "Calculation of actinide solubilities in WIPP SPC and ERDA6 brines under MgO backfill scenarios containing either nesquehonite or hydromagnesite as the Mg-CO_3 solubility-limiting phase.") Since the results with nesquehonite were quite different for the (IV) actinides, they are reproduced here together with the results reported in the draft manuscript.

Conditions	+4 act., molar Salado (SPC)	+4 act., molar Castile	log fugacity (CO_2)
CCA calc.	4 E-6	6 E-9	-6.9
No backfill	5 E-4	7 E-5	0 to 2
5424 hydromag.	1 E-8	4 E-8	-5.5
4323 hydromag.	2 E-8	5 E-8	-5.39
Nesquehonite	6.3 E-4	1.0 E-3	-3.8

Note that with nesquehonite present, the solubility of the +4 actinides is calculated to be higher than it is with no backfill present. pcH for Salado conditions is calculated to be 9.4 and for Castile, 9.9.

The predictions of solubility in the presence of hydromagnesite are lower than the experimental results for Th discussed above, but are similar to the results found for Pu in the presence of hydromagnesite and Fe. No experimental data on the solubility of Th or Pu in the presence of nesquehonite is yet available.

Complex ion formation

Discussions in the previous sections have shown that the inorganic anions most likely to affect actinide (IV) solubility through complex ion formation under WIPP brine conditions are hydroxide and carbonate ions. Sulfate ion has been shown in experiments with U(IV) to have no significant effect on overall solubility over the range of variation in sulfate content expected for the WIPP.

The remaining possibility for complex ion formation comes from the waste materials, themselves. Citrate, which forms a very stable complex ion with Th, is present in large amounts in the waste inventory. The solubility calculations for the actinides in brines with and without MgO are discussed in Appendix B. These calculations assume homogeneous equilibria, which for actinides in the absence of complexing ligands from the waste is probably an adequate estimate. For the case where organics are present, the organics are also treated by SOTERM as if they were homogeneously dissolved in 29,841 m^3 of brine.

To model the behavior of Pu with citrate, we must 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.

Another possible ligand for increasing Pu(IV) solubility comes from the degradation of cellulose. 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).

To obtain a more accurate estimate of the effect of citrate and cellulose degradation products on Pu solubility in the event of human intrusion, calculations that use Pu complexes formed inside a waste drum and model the mixing of that relatively concentrated brine with the average repository brines must be done, taking into account the time scales for mixing and the possibility that the intrusion event may release some brine from waste drums that has not had an opportunity to mix with the average repository brines. The development of an appropriate scenario is discussed further in the next section.

The conclusion given in the CCA SOTERM appendix that EDTA complexes will not increase actinide solubility is probably correct, since the amount of EDTA is small and the Ni and Fe complexes have stability constants that are similar to those for the actinides. It is not shown, and is probably not true, that the more abundant citrate inventory will not increase actinide solubility, especially for Pu.

Scenarios for dissolution of plutonium

Analyses of the long-term performance of the WIPP repository have shown that the only likely cause for significant releases of radioactivity would come as the result of human intrusion into the repository. One pathway for release involves drilling into the repository level, flooding of the repository with brine, and then flow of the brine through the overlying Culebra dolomite aquifer. This pathway would require considerable time before radionuclides would reach the accessible environment and, in this case, the model of homogeneous brine compositions averaged over the whole repository at the time of the release is probably appropriate. For this scenario, the large volume of brine (29,841 m^3) discussed in the SOTERM calculations is probably needed.

Another human intrusion release scenario involves drilling through the repository and reaching the underlying Castile formation, in which there are pockets of pressurized brine. If a pocket of pressurized brine were to be encountered during drilling, it is possible that it might rise up the drill hole, through the repository, and up to the surface very rapidly. The only waste encountered in this case might be that in a few drums that were in the immediate path of the drill hole. These drums might contain low Pu concentrations and little or no citrate ions or cellulose degradation products, or they might contain the maximum allowed Pu concentration and sufficient citrate or cellulose degradation products to fully complex the Pu. The brine composition would be determined by the local, internal environment in the waste drum, rather than by the grand average of the repository.

As an illustration, the volume of brine that would be associated with this release scenario may be estimated by assuming a small diameter exploratory drill hole of about 0.01 m^2 area (a bit over 10 cm diameter drill core) and a hole depth of about 900 m. The volume to fill this hole would be 9 m^3. A reasonable volume for the release of brine before it was capped off would be about 100 m^3, or about 10,000 liters of brine. This brine could be assumed to contain the contents of two waste drums, each containing 10g Pu and 10 moles of citrate. The brine inside a crushed waste drum with these inventory amounts could be modelled assuming the drum material was actively corroding to provide Fe(II) at equilibium concentration with appropriate citrate complexation as well as the Pu(IV) citrate complex. The amount of such brine could be quite small (< 1 L) or moderate (10-30 L). This assumed concentrated brine could then be intercepted by the drill hole and the brine rising from the Castile formation, providing dilution of the concentrated brine, but probably not a major change in speciation. The appropriately diluted brine would then be the material that would be assumed to reach the surface.

The construction of the CCDF for assessment of compliance with 40 CFR 191 would then involve a selection of model realizations with the release from a pressurized brine and a probability distribution of whether the drums that might be intersected by the drill hole were those with high Pu or with low Pu. This method for handling heterogeneous waste distributions and heterogeneous equilibria in the respository would be rather simple to implement, at least on the level of exploratory calculations.

Suggestions for future work

Experimental work

Performance predictions for WIPP are currently done using equilibrium thermodynamic modelling of brine chemistry and with Th as the representative of the (IV) actinides. The calculated Th concentrations have internal inconsistencies (described in Appendix B) with respect to both the total solubility and the speciation of Th under conditions with similar brine composition. Experimental work on systems that contain Pu itself, rather than Th as a surrogate, have been started and should be continued. Results from these and future experiments should be compared with existing experimental results on U(IV) compounds.

If MgO will be used in the repository to control pH and to attempt to control carbon dioxide fugacity, experiments using brines with nesquehonite and brines with hydromagnesite should be conducted. Carbon speciation should be measured in these experiments as a function of reaction progress, as well as the evolution of the brine chemistry. These parameters will be needed if the longer term solubility of Pu in these systems is to be modelled. Redox state of Pu in solutions should be measured; methods that might be used are direct spectroscopy at relatively high concentrations and valence-specific solution extraction methods at low concentrations.

The stability constant for formation of citrate complex ions with Pu(IV) should be determined. The sensitivity, if any, of the value of the stability constant on brine composition should be evaluated. Experiments in systems that contain abundant citrate and Pu together with metallic iron and iron corrosion products formed under WIPP-relevant conditions should be done to evaluate the ability of

Fe(II) in solution to compete for citrate ion in complexes. Sequential dilution of brine with Pu-citrate complexes in solution by adding samples of that brine to solutions containing brine with metal and corrosion products should be conducted to provide validation of the calculations suggested below.

Thermodynamic properties and models

Use of Th to model the behavior of all actinide (IV) elements requires that (1) the chemistry of all actinide (IV) elements in brines is closely similar and (2) that the data base for species formation and solubility as well as for activity coefficients of Th(IV) species in brines is sufficiently well known. The differences found between Th concentrations calculated by Novak and Moore (1996) and those measured by Rai et al. (1997), and the differences between the calculations for Th and the experimental data for U(IV) indicate that one or both of those requirements is not met.

Several work areas need to be undertaken in order to improve the reliability of the calculations. First, the calculations should be done using data for Pu and the values for solubility and complex ion formation contained in the peer-reviewed data compilation prepared by OECD/NEA. This work has been underway for about 10 years and has had many man-years of effort from the members of the specialist review committee. Even though small changes may be made between the current draft document and its final publication, it is likely that a significant improvement in the consistency of the calculated results and the findings in solubility and speciation experiments could be found if this source were used for the basic thermodynamic data.

DePablo et al. (1995) reported calculations of U(IV) solubility in brines using an equilibrium thermodynamic modelling code developed by the US Geological Survey. It would be instructive to compare the results of calculations of Th solubility using the same code and data base to the reported results of Novak and Moore (1996). In particular, a comparison of the calculated activity coefficients for dissolved species using each code would be useful. For highly charged species such as $Th(CO_3)_5^{6-}$ it is extremely difficult to estimate the activity coefficient using calculational methods. Comparison of the species included in the calculations as well as the results of speciation and solubility predictions for Th would be interesting and might give an insight into the uncertainties that exist in the calculation of solubilties for these systems.

A sensitivity analysis should be conducted to determine the effects of uncertainties in both the solubility measurements and stability constant determinations as well as the estimation of Pitzer parameters on the final calculated solubility. This would involve a “Monte Carlo” type of sampling procedure that selects a value within the range of +/- appropriate to the solubility product for a given compound and then values for each of the complex ion stability constants within their range of data uncertainties. A similar process would be used for the calculation of the Pitzer coefficients. Results of 30 to 40 calculations using this type of sampling method should give a reasonable indication of the real range of combined uncertainty in the calculations.

Release scenario calculation

A scenario for release via human intrusion that involves release of brine with concentrated Pu-citrate content via mixing with a larger volume of brine and transport through the Culebra aquifer should be done. This calculation can be done as a simple, sequential dilution model in which 10 liters of initial Pu-citrate-containing brine is mixed with 10 liters of Salado brine equilibrated with appropriate minerals and Fe(II) corrosion products. The second calculation would then mix this 20 liter volume of brine with another 20 liters of Salado brine. Ten steps of mixing would give a brine volume of 10,000 liters. The pattern of speciation changes in Pu and the overall Pu solubility calculated could then be compared to the sequential dilution experiments discussed above. If the results agree, a level of validation is achieved for the calculations. If the results disagree, insight into requirements to improve the data base and calculational methods should be gained.

References

I. AlMahamid, K. A. Becraft, N. L. Hakem, R. C. Gatti, and H. Nitsche (1996) Stability of various plutonium valence states in the presence of NTA and EDTA, Radiochimica Acta 74, 129-134.

L. Chaturvedi, W. W.-L. Lee, M. K. Silva, T. M. Clemo, and R. H. Neill (1997) Evaluation of the long-term integrity of WIPP, in WM'97 Proceedings: HLW, LLW, Mixed Wastes and Environmental Restoration - Working Towards a Cleaner Environment, March 2-6, 1997, Tucson, AZ.

G. R. Choppin (1990) Actinide Speciation in Spent Fuel Leaching Studies, in Mat. Res. Soc. Symp. Proc. 176, V. M. Oversby and P. W. Brown, eds., 449-456.

J. E. Cross, F. T. Ewart, and B. F. Greenfield (1989) Modelling the behaviour of organic degradation products, Mat. Res. Soc. Symp. Proc. 127, W. Lutze and R. C. Ewing, eds., 715-722.

J. DePablo, J. Giménez, M. E. Torrero, and I. Casa (1995) Mechanism of unirradiated UO_2 (s) dissolution in NaCl and $MgCl_2$ brines at 25°C, Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 609-615.

A. R. Felmy, D. Rai, J. A. Schramke, and J. L. Ryan (1989) The solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Brines, Radiochimica Acta 48, 29-35.

B. F. Greenfield, A. D. Moreton, M. W. Spindler, S. J. Williams, and D. R. Woodwar (1992) The effects of the degradation of organic materials in the near field of a radioactive waste repository, in Mat. Res. Soc. Symp. Proc. 257, C. G. Sombret ed., 299-306.

C. F. Novak and R. C. Moore, SNL Tech Memo dated March 28, 1996, "Estimates of Dissolved Concentrations for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Conditions." (Referenced in US DOE Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, Appendix SOTERM, October 1996. Stated to be on file in Sandia WIPP Central File A: WBS 1.2.0.7.1; WBS 1.1.10.1.1: WPO 36207.)

E. Östhols, J. Bruno, and I. Grenthe (1994) On the influence of carbonate on mineral dissolution: III. The solubility of microcrystalline ThO_2 in CO_2-H_2O media, Geochim. Cosmochim. Acta 58, 613-623.

D. Rai, A. Felmy, D. A. Moore, and M. J. Mason (1995) The solubility of Th(IV) and U(IV) hydrous oxides in concentrated $NaHCO_3$ and Na_2CO_3 solutions, in Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 1143-1150.

D. Rai, A. R. Felmy, D. A. Moore, and M. J. Mason (1997) Development of thermodynamic data for predicting the solubility of actinide compounds in highly concentrated brines, Final report for FY 1997, Sandia Contract No: AT-8746.

Sandia (1997) “Chemical Conditions Model: Results of the MgO Backfill Efficacy Investigations”, Sandia National Laboratories (no author names), April 23, 1997, Draft.

R. F. Weiner, D. E. Hobart, C. D. Tait, and D. L. Clark (1996) Analysis of Actinide Oxidation States in the WIPP, Sandia National Laboratories, Waste Isolation Pilot Plant, WBS 1.1.10.1.1.

Appendix A

Review of “Chemical Conditions Model: Results of the MgO Backfill Efficacy Investigations”, Sandia National Laboratories (no author names), April 23, 1997, Draft.

This paper describes some experiments in which MgO in the form of small pellets (2 to 4 mm in size) or MgO “fines” (0.5 to 1.0 mm) were reacted with Castile and Salado brines (presumably synthetic, but the text does not address this point).

The experiments produced reaction products that are predominantly nesquehonite ($MgCO_3 \cdot 3H_2O$) with the later appearance of a phase that could not be positively identified, but was tentatively identified as $MgCO_3 \cdot 3H_2O \cdot MgCl(OH)$ (PDF7-278) (no name given). The chemistry of this phase is quite different from that of hydromagnesite $[(MgCO_3)_4 \cdot Mg(OH)_2 \cdot 4H_2O]$. Despite this, the paper claims on page 30 that “we observed that hydromagnesite, with a loose platy habit, is the favored metastable phase in our experiments, rather than nesquehonite.” (See comment 4 below for a more detailed discussion.)

The concentration of an element in solution is the sum of all of the species concentrations in which that element is present. Usually, one species predominates as the most soluble for a given element under a given set of conditions, and the concentration of that species is determined by the solubility of the most soluble solid phase that results in that species being formed. That phase will continue to control the solubility so long as it is present in the system, even if other, more stable, phases are also present. For the set of possible conditions with MgO backfill present, and assuming the absence of ligands for the actinides that result in even higher solubility species, the phase that results in highest (IV) actinide solubility is nesquehonite. So long as nesquehonite may be present in the WIPP repository, the solubility of (IV) actinides must be modelled using calculations that include it as a member of the phase assemblage. Since the production of CO_2 is assumed to persist over periods of thousands of years, and since nesquehonite is observed to be formed early in the sequence of phases formed when carbon dioxide reacts with MgO in the backfill, we must assume that nequehonite will be present over thousands of years, even if it can be shown that the conversion of a particular amount of nesquehonite to a less soluble phase occurs over a time scale of a few hundred years.

As shown in item 7 of the detailed comments, the solubility of (IV) actinides with nesquehonite present is even higher than that calculated for the case with no MgO present. If nesquehonite must be considered as present for most of the performance period of the repository, it would seem that the addition of MgO does not enhance the performance of the repository, but rather adds to the uncertainties to be considered, if our attention is limited to the case of the (IV) actinides. For the (III) and (V) actinides, the MgO does seem to reduce the solubility considerably, even with nesquehonite present (data in Novak, 21 April 1997 memo). Since Pu is the dominant actinide, and since (IV) is the most likely oxidation state for Pu under WIPP conditions, there might be good cause to reconsider the inclusion of MgO as backfill in the repository.

Detailed comments:

1. p. 5, bottom. "There is evidence in the literature that MgO can exhibit a bactericidal characteristic. However, there [*sic*] studies supporting this assertion were performed under conditions far removed from those expected in the WIPP and no direct correlation could be drawn from the literature conditions to those expected at WIPP. Therefore, no beneficial credit was taken for the potential bactericidal effect of MgO and the microbial gas generation rates were left unchanged."

> The microbes are assumed to decompose cellulose to CO_2 and methane. If the microbes are not present, chemical degradation of cellulose at high pH is likely to result in compounds that can form complexes with actinide elements and increase their solubility. See, for example, the paper by J. E. Cross, F. T. Ewart, and B. F. Greenfield in Mat. Res. Soc. Symp. Proc. Vol. 127, W. Lutze and R. Ewing, eds., pp. 715-722, 1989. Absence of microbes may provide negative as well as positive contributions to the potential performance of the repository.

2. p.2, middle. "Arrhenius plots assembled with laboratory synthesis of magnesite at 60°C for 7 years and at higher temperatures suggest that magnesite will form within several hundred years in the WIPP." And, p. 19, "Nesquehonite is also temperature sensitive, but is stable well within the temperature range anticipated at the WIPP; it will convert to hydromagnesite above about 60°C (Lippmann, 1973)." The extrapolations using Arrhenius plots are discussed in more detail on pages 35-6.

> The use of data obtained outside of the field of temperature stability of a phase to estimate kinetics of converstion of that phase to another phase is invalid. In addition, the phase into which nesquehonite converts is stated on p. 19 to be hydromagnesite, not magnesite.

3. p. 13. The pH curves vs reaction time show Salado brine with both the "coarse" and "fine" MgO with pH about 6, and the Castile samples to have pH about 6.8. In the figure caption, it is claimed that "The difference between the Salado and Castile curves reflects differences in the mineralogy of the coatings formed in these two brines."

> This statement seems to conflict with the reaction product discussion in the manuscript on page 20 ff.

4. p. 30. "As describe [*sic*] in Section 4, we observed that hydromagnesite, with a loose platy habit, is the favored metastable phase in our experiments, rather than nesquehonite."

> This statement conflicts with the content of section 4. Hydromagnesite was never identified in any of the experiments. Nesquehonite was described as the abundant and identifiable phase in most of the experiments.
>
> The reaction sequence observed is decribed on p. 20 ff. in the draft manuscript. There is no clear difference in the phase assemblage claimed in the two brine

systems, only in the morphology of the phases; see p. 27 top in the draft manuscript. From what can be seen in the text, nesquehonite, once formed, persists in the system even if a new, unidentified phase also forms later.

The first phase observed (at point c in the model of reaction progress) is stated to contain C, O, and Mg, with very little Cl. It is interpreted to be protohydromagnesite on p. 21, top. Note: protohydromagnesite is not the same phase as hydromagnesite.

"For the coarse fraction samples, nesquehonite formation had become the dominant alteration process by day two for the Salado fraction and day three for the Castile fraction." (p. 21)

For the fines, at day four there was no nesquehonite observed in either brine, but the original alteration product (noted above as point c) was thicker and is now referred to as "hydromagnesite-like". At day ten, the Salado brine sample with MgO fines showed nesquehonite as a mat over a Cl-rich version of the "hydromagnesite-like" material. (p. 21, middle and Fig. 4-5).

At stage f in the reaction progress model, the samples (not stated whether it is coarse fraction, fine fraction, or both) develop an interlocking mesh of fine, platy crystals, which is interpreted to be protohydromagnesite containing a detectable amount of Cl.

On p. 27, the appearance of the new phase is claimed to be related to the presence of a high Mg concentration. The phase identification was tentative. "Although the SEM photographs show the material to be crystalline, the small crystal size has made it very difficult to get positive identification by x-ray diffraction. The best, though still highly tentative, identification arises from the comparison of the fines recovered from a 10-day treatment. In the case of the Castile coarse sample, a very clean pattern for pure nesquehonite was obtained. The dominant peaks in the Salado coarse sample were also nesquehonite, but a comparison with the Castile pattern showed that a few very small new peaks were present. These could be indexed to the material $MgCO_3 \cdot 3H_2O \cdot MgCl(OH)$ (PDF7-278)." Six lines later, the manuscript claims "The parallel between this new material and hydromagnesite is quite evident. Both this phase and hydromagnesite $[(MgCO_3)_4 \cdot Mg(OH)_2 \cdot 4H_2O]$ consist of mixtures of magnesium carbonate, magnesium hydroxide, and waters of hydration." This analogy would imply that most of the other phases listed on page 18 would also be equally closely related to the new material. The presence of Cl in the new material is, apparently, not considered to be important.

On. p. 29, the results of the "tea-bag" experiments are discussed. The samples with longest reaction times were for 19 days. "In the 19-day samples, masses of nesquehonite needles are readily observable in the pore spaces between the grains."

5. p.32. “Given the extremely slow precipitation rate detailed by the low pCO_2 in the repository, we expect that nesquehonite will not form. The favored metastable phase is hydromagnesite.”

It is difficult to reconcile this claim with the experimental evidence presented in Section 4 of the manuscript, especially since hydromagnesite has not been seen to form in any of the experiments described in that section.

6. In the figure caption for Fig. 5-5, it is stated “In our experiments, nesquehonite, [*sic*] is initially formed but converts to hydromagnesite, probably through the protohydromagnesite intermediary.”

This statement misrepresents the experimental results. The only phase that was positively identified was nesquehonite, which was found in abundance in nearly all of the experiments discussed in the draft manuscript. The reaction path described at the top of page 37 as “possible” is just that - possible, not definitive.

7. p. 38. “As shown previously, hydromagnesite has been observed and predicted to be the metastable phase possibly formed in the repository which then ages to form magnesite. Model predictions were performed to predict the actinide solubilities which could occur during these transient periods. To perform the model predictions, hydromagnesite had to be added to the actinide solubility database.”

As stated above, hydromagnesite was never identified in the experiments described in the draft manuscript. In other materials available from Sandia, it was seen that calculations were also done with nesquehonite (C. F. Novak memo to R. Vann Bynum dated 21 April 1997, “Calculation of actinide solubilities in WIPP SPC and ERDA6 brines under MgO backfill scenarios containing either nesquehonite or hydromagnesite as the Mg-CO_3 solubility-limiting phase.”) Since the results with nesquehonite were quite different for the (IV) actinides, they are reproduced here together with the results reported in the draft manuscript.

Conditions	+4 act., molar Salado (SPC)	+4 act., molar Castile	log fugacity (CO_2)
CCA calc.	4 E-6	6 E-9	-6.9
No backfill	5 E-4	7 E-5	0 to 2
5424 hydromag.	1 E-8	4 E-8	-5.5
4323 hydromag.	2 E-8	5 E-8	-5.39
Nesquehonite	6.3 E-4	1.0 E-3	-3.8

pcH for Salado conditions is calculated to be 9.4 and for Castile, 9.9.

Note that with nesquehonite present, the solubility of the +4 actinides is higher than it is with no backfill present. This suggests that the addition of MgO backfill may not provide clear improvement in performance, but may add significant uncertainty in performance predictions.

Appendix B

Comments on SNL Tech Memo by C. F. Novak and R. C. Moore dated March 28, 1996, "Estimates of Dissolved Concentrations for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Conditions." (Referenced in US DOE Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, Appendix SOTERM, October 1996. Stated to be on file in Sandia WIPP Central File A: WBS 1.2.0.7.1; WBS 1.1.10.1.1: WPO 36207.)

This memo describes the general method used to calculate the solubilities of actinides for use in the CCA and gives the results for several sets of calculations. The database used is cited, but not included in the memo.

Solubilities were calculated using an equilibrium thermodynamic speciation code "FMT", which employs Pitzer-type interaction parameters to obtain activity coefficients for dissolved species.

Equilibrium thermodynamics for solution chemistry requires the use of the activity, a, of species in equations that describe solubility or complex ion formation. The activity of a species is related to its concentration in solution by the relationship

$a = \gamma m$ where γ is the activity coefficient and m is the concentration of the species in moles per kg of solution.

The solubility product, K_{eq}, of the salt AB in an aqueous solution can then be written as

$$K_{eq} = a_{A+}a_{B-}/a_{AB} = (\gamma_{A+}m_{A+})(\gamma_{B-}m_{B-})$$

The term a_{AB} is eliminated because the activity of a pure solid is unity. The terms such as γ_{A+} are the activity coefficients of the dissolved ionic species. For an ideal solution, which generally means solutions near infinite dilution (very little solute), these terms approach unity and the solubility may be approximated by the product of the molal concentrations. At low total dissolved solids for aqueous solutions, molal concentration (m) approaches molar concentration (M = moles/liter).

When solubilities are calculated for systems with many components, a group of equilibrium solubility equations must be solved simultaneously with a group of association relationships that describe formation of complex ions in solutions. The association relationships generally are limited to the attachment of an anionic ligand, L, to a cation, A+.

$\beta_{1,1} = a_{AL} / a_{L-}a_{A+}$ where the subscript 1,1 indicates that the complex consists of 1 cation and 1 ligand.

To solve the system of equations, data are needed for the equilibrium solubility constants, the association constants for ligands with cations, and the activity coefficients for all solution species.

What is available from direct measurements is the equilibrium solubility of compounds under various conditions at a fixed ionic strength in some noncomplexing electrolyte such as 0.5M $NaClO_4$ and similar data for association reactions for ligands and cations. These data must first be extrapolated back to zero ionic strength to get true equilibrium values for infinite dilution and then extrapolated up to the ionic strength of the actual solution. For dilute natural groundwaters, the zero ionic strength data are generally used directly. For brines, the use of some scheme such as Pitzer parameters is needed to provide the activity coefficients for the calculations.

Chemical solutions with many components are routinely modelled using computer codes such as EQ3, or, in the case of the WIPP project, FMT. These codes use a database of equilibrium, zero ionic strength data for solubility and complex ion formation, a method to calculate activity coefficients as a function of solution chemistry and solution ionic strength, and a numerical method to solve a large number of simultaneous equations. Errors and uncertainties can enter the calculations from any and all of these areas. In addition, since the codes are for equilibrium conditions, when systems occur with long-lived metastable species the code user must select which species will be surpressed in the calculations. This means that the surpressed species are eliminated from the calculations so that less stable species can control solution concentrations. For example, if hydromagnesite is to be allowed to be present, the more stable magnesite phase must not be included in the calculations. The user of the code must select the phases that will not be allowed to form.

The types of difficulties that can be encountered in using computer modelling of solution chemistry are

(1) Data for solubility or complex ion formation are not available for the species needed or are incorrect.

(2) Insufficient data exist to allow accurate estimation of ion interactions at high ionic strength. (Activity coefficients cannot be accurately estimated.)

(3) Data for solubility or for complex formation are known, but are not included in the data base used by the code in question.

(4) Incompatible thermodynamic properties data are included in the data base. (This can cause erratic results in calculations.)

(5) Calculational problems related to the algorithms used to solve the simultaneous equations. (This can result in errors from accumulation of rounding errors in calculations or from multiplication of uncertainties through use of a convoluted calculational path.)

It is rare that the accuracy of computer calculations of thermodynamic equilibria for complex systems can be determined directly. In most cases, one must examine the results of calculations for consistency with experiments on related, but not identical, systems. It is also important to examine the results of calculations for internal consistency, i.e., when large changes occur in the calculated concentration of a solution species, are these accompanied by other changes in the solution species that would be expected.

When I examined the calculational results in the memo by Novak and Moore, I found inconsistencies both internally and with respect to relevant published work. These are discussed below.

Novak and Moore did a series of calculations in which they stepwise equilibrated a brine composition with selected solids, actinides, more selected solids, and organics in the solution phase. The sequence of calculations was

(1) Brine alone
(2) Brine plus halite and anhydrite
(3) Brine from step 2 plus Am(III) + Th(IV) + Np(V) until an actinide solid phase precipitated for each actinide
(4) Brine from step 3 plus brucite and magnesite
(5) Brine from step 4 plus organic ligands.

In addition, steps 4 and 5 were done with saturation with portlandite and calcite instead of with brucite and magnesite.

Selected calculation results are presented in Table 1 as element concentrations and in Table 2 as species concentrations in mol/kg. The changes in major solutions chemistry in going from step 1 to step 3, which is the first result shown in Tables 1 and 2, were

ERDA brine: sodium increased from 5.63 m to 6.22 m, and pmH decreased from 6.74 to 5.84, accompanied by changes in carbon dioxide and carbonate species related to pH and compex ion formation.

Salado brine: sodium increased from 2.06 m to 2.9 m, and pmH increased from 4.11 to 5.63, again with changes in carbon dioxide and carbonate species.

We will discuss only the calculations for Th solubility and speciation here. For the case with actinides plus brine plus saturation with halite and anhydrite, two sulfate complexes with thorium appear as the sole reason for high solubility in the Salado brine case and are significant contributors to high solubility in the ERDA brine case. The abundance of these calculated species does not appear to be strongly affected by the factor of 4 difference in sulfate ion concentration in the two brines. When calculations are then done for addition of brucite and magnesite, the sulfate ion concentrations in solution remain about the same, but the Th sulfate complexes become insignificant. This occurs together with a calculated decrease in total Th solubility. Since the only major change in brine chemistry for the ERDA case is an increase in pH and accompanying changes in carbonate equilibria, the Th sulfate solution complexes should remain dominant. Their absence in the speciation results for the step 4 cases suggests that there are major calculational problems with the FMT code and its data base.

Experimental data for the solubility of UO_2 in brines of NaCl with similar ionic strength (pH = 7.7) and $MgCl_2$ with higher ionic strength (pH = 4.7) under reducing conditions in the absence of carbon dioxide gave U^{4+} concentrations of 2.8 x 10^{-7} m and 3.1 x 10^{-7} m, respectively (DePablo et al., 1995). These results are compared to calculations for thorium by Novak and Moore in the following table. (See Tables 1 and 2 at the end of this appendix for detailed results.)

Table B-1: Comparison of experimental determination of solubility for U with calculated solubility for Th.

Brine type	Experimental value UO_2, DePablo et al.	Calculated value ThO_2, Novak and Moore
NaCl/ERDA	2.8 x 10^{-7} m	3.9 x 10^{-3} m
$MgCl_2$/Salado	3.1 x 10^{-7} m	4.4 x 10^{-4} m

The Th solubility in the ERDA brine was calculated to be dominated by the pentacarbonate complex; however, the amount of soluble Th sulfate complexes was calculated to be 7 x 10^{-4} m. For the Salado brine, the calculated Th solubility was due almost completely to the soluble sulfate complexes. Since DePablo et al. had no carbon dioxide in their system, the soluble species should be present as hydroxy or sulfate complexes only. The experimental results are three and four orders of magnitude lower than those calculated by Novak and Moore for Th. Since the WIPP project bases their model for (IV) actinide solubility on the assumption that all (IV) actinide solubilities can be calculated using Th as the model, this discrepancy between calculations and experiments under similar conditions is significant.

The Th sulfate complexes used in the calculations were proposed by Felmy and Rai (1992) when they reinterpreted data published originally in 1963; they do not consider the monosulfate complex. Data for sulfate complexes of Pu being considered for use in the international compendium of thermodynamic data for Pu and Np under preparation by OECD/NEA contains recommended values for a mono-sulfate, $Pu(SO_4)^{2+}$, and a disulfate, $Pu(SO_4)_2$, complex, rather than the di- and tri-sulfate complexes, $Th(SO_4)_2$ and $Th(SO_4)_3^{=}$, used in the Novak and Moore calculations (K. Spahiu, personal communication). This suggests that either (1) the complexes used to model Th were incorrect, or (2) that Th is not a good surrogate for Pu in its behavior with respect to sulfate complexes. In either case, the calculations done for Th would not be valid for use in estimating Pu solubility.

Another problem that is evident in the Novak and Moore calculations concerns the carbonate species calculations. At low pH in the Castile brine, the dominant soluble Th species is calculated to be $Th(CO_3)_5^{6-}$ with very minor amounts of $Th(OH)_3CO_3$. At higher pH (9.9), the two species are calculated to be about equal in importance in Castile brine, but with the solubilities in the 2 to 4 x 10^{-9} range. In Salado brine, the pentacarbonate complex is absent at pH 5.6 (nearly the same pH as for the equivalent Castile calculation, which shows this complex present at 3 x 10^{-3}m), but appears at 3 orders of magnitude higher than Castile calculated concentrations at pH 9.4, with similar total dissolved carbonate species in the two cases. These internal inconsistencies in calculated results point to problems in the calculational methods used and/or the data base parameters selected. In addition, the species predominance at low pH should be the opposite of that calculated for the Castile brine. The stabilitiy constants for these species were determined by Östhols et al. (1994); a graphic display of the progression of species as a function of pH is given in their paper. The pentacarbonate complex is dominant at high pH, while the hydroxycarbonate species is important at lower pH.

An additional problem with the calculated carbonate species for Th is that the pentacarbonate complex is predicted to exist in solutions with only micromolal carbonate concentrations. In general, this species is not important until carbonate concentrations are above 0.1 molal. See, for example, Rai et al. (1995). Discussion with K. Spahiu confirmed that behavior of Pu carbonate complexes could be expected to be similar to Th and to require concentrations in the > 0.1 m carbonate range.

It should be noted that conclusions drawn by Novak and Moore concerning the lack of importance of organic complexation in the determination of Th solubilities are invalidated since their basic calculations for Th solution species appear to contain a number of significant errors.

References

J. DePablo, J. Giménez, M. E. Torrero, and I. Casa (1995) Mechanism of unirradiated UO_2 (s) dissolution in NaCl and $MgCl_2$ brines at 25°C, Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 609-615.

E. Östhols, J. Bruno, and I. Grenthe (1994) On the influence of carbonate on mineral dissolution: III. The solubility of microcrystalline ThO_2 in CO_2-H_2O media, Geochim. Cosmochim. Acta 58, 613-623.

A. R. Felmy and D. Rai (1992), An aqueous thermodynamic model for a high valence 4:2 electrolyte Th^{4+}-SO_4^{2-} in the system Na^+- K^+- Li^+-NH_4^+- Th^{4+}- SO_4^{2-} - HSO_4^- - H_2O to high concnetrations, J. Soln. Chem. 21, 407-423.

D. Rai, A. Felmy, D. A. Moore, and M. J. Mason (1995) The solubility of Th(IV) and U(IV) hydrous oxides in concentrated $NaHCO_3$ and Na_2CO_3 solutions, in Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 1143-1150.

Table 1: Results of model calculations by Novak and Moore(1996) in concentrations of moles/kg brine. Equilibrations of Castile-like brine (ERDA) and Salado-like brine with anhydrite and halite plus actinides with and without MgO or CaO.

Element	ERDA-HA-An		Salado-HA-An		
	no MgO	with MgO	no MgO	with MgO	with CaO
Hydrogen	111	111	111	111	111
Oxygen	56.5	56.5	55.8	53.9	55.6
Sodium	6.22	6.2	2.9	4.69	3.5
Potassium	0.11	0.11	0.865	1.05	1.06
Magnesium	0.0214	0.0443	1.62	0.51	6.0 E-6
Calcium	0.0112	0.0133	0.0305	0.0331	1.31
Chlorine	5.98	5.97	6.95	6.67	7.12
Sulfur	0.189	0.191	0.0529	0.06	0.002
Carbon	1.86 E-2	3.15 E-5	1.15 E-2	4.08 E-5	5.87 E-6
Boron	0.0709	0.0708	0.0225	0.0272	0.0244
Bromine	0.0124	0.0124	0.0112	0.0136	0.0122
Th(IV)	3.88 E-3	6.78 E-9	4.37 E-4	4.98 E-6	1.16 E-9
Am(III)	4.49 E-4	4.12 E-7	2.57 E-4	4.39 E-6	1.25 E-9
Np(V)	1.74 E-4	7.53 E-6	1.78 E-5	7.64 E-6	4.85 E-6
pmH	5.843	9.893	5.63	9.366	12.124
Solid phases	halite	halite	halite	halite	halite
	andhydrite	andhydrite	andhydrite	andhydrite	andhydrite
		brucite		brucite	brucite
		magnesite		magnesite	portlandite
		glauberite		Mg-oxychloride	calcite
					Ca-oxychloride
	AmOHCO3(s)	AmOHCO3(s)	AmOHCO3(s)	Am(OH)3	Am(OH)3(s)
	ThO2(am)	ThO2(am)	ThO2(am)	ThO2(am)	ThO2 (am)
	KNpO2CO3.2H2O(s)	KNpO2CO3.2H2O(s)	KNpO2CO3 2H2O(s)	KNpO2CO3.2H2O(s)	NpO2(OH)(aged)

Table 2: Solution species concentrations in brines (from Novak and Moore, 1996) in moles/kg
Only species involving major ions, sulfate, carbonate, and actinides are given.

	Castile		Salado		
Species	ERDA6-HA-An	ERDA-HA-An-Mg	SPC-HA-An	SPCHA-An-Mg	SPC-HA-An-Ca
Na+	6.22	6.2	2.9	4.69	3.5
K+	0.11	0.11	0.865	1.05	1.06
Ca++	0.011	0.011	0.03	0.032	1.29
Mg++	0.071	0.039	1.67	0.496	3.6 E-6
MgOH+	2.1 E-8	4.2 E-4	1 E-6	1.7 E-3	4.4 E-6
H+	1.4 E-6	1.3 E-10	2.3 E-6	4.3 E-10	7.5 E-13
Cl-	5.98	5.97	6.95	6.67	7.12
SO4=	0.187	0.191	5.16 E-2	6.02 E-7	1.97 E-3
HSO4-	4 E-6	3.6 E-10	8 E-7	3 E-10	1 E-14
HCO3-	8.1 E-4	7.1 E-6	2.39 E-3	1.78 E-6	1.4 E-10
CO3=	8.0 E-8	8.0 E-6	6.4 E-7	8.3 E-7	3.1 E-7
CO2(aq)	1.4 E-3	1.2 E-9	9.1 E-3	1.2 E-9	6 E-16
NpO2+	1.7 E-4	1.7 E-6	1.7 E-5	2.4 E-6	7.3 E-8
NpO2OH(aq)	1.9 E-9	2.1 E-7	1.5 E-10	1.2 E-7	2.4 E-6
NpO2(OH)=	NEGL.	1.0 E-9	NEGL.	1.8 E-10	2.4 E-6
NpO2CO3-	6.6 E-7	6.3 E-7	4.2 E-7	1.2 E-7	1 E-9
Am+++	3.4 E-4	7.8 E-11	1.94 E-4	3.2 E-9	1.4 E-17
AmOH++	1.1 E-4	2.7 E-7	5.6 E-5	3.8 E-6	1.2 E-11
Am(OH)2+	5.0 E-9	1.4 E-7	1.8 E-9	5.7 E-7	1.1 E-9
AmCO3+	3.2 E-6	7.2 E-11	7.3 E-6	2.9 E-10	3 E-19
Th(SO4)2(aq)	1.35 E-5	9 E-22	1.4 E-5	1 E-20	0
Th(SO4)3=	5.9 E-4	4 E-20	4.2 E-4	8 E-20	0
[Th(CO3)5]6-	3.27 E-3	3.7 E-9	0	5 E-6	0
Th(OH)3CO3-	2.0 E-7	1.8 E-9	6.9 E-7	5 E-10	1 E-13
Th(OH)4(aq)	1.3 E-9	1.3 E-9	1.1 E-9	1.2 E-9	1.2 E-9

APPENDIX C

Comments on Appendix SOTERM to the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant dated October 1996.

Comments will be confined to those sections of the Appendix that deal with estimation of the dissolved actinide portion of the source term as it applies to plutonium. Most attention will be focused on Pu(IV), which is the most probable oxidation state under WIPP conditions. The section concerning the potential for colloidal transport (6) is quite thorough and, if anything, overestimates the amount of actinide that might be transported as the result of the presence of colloids in the brine.

The solubility calculations for the actinides in brines with and without MgO are discussed in Appendix B. These calculations assume homogeneous equilibria, which for actinides in the absence of complexing ligands from the waste is probably an adequate estimate. For the case where organics are present, the organics are also treated by SOTERM as if they were homogeneously dissolved in 29,841 m^3 of brine. There are some inconsistencies in the table of inventories and molal concentrations (see item 8 below); however, this problem is small when compared to the failure to 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 an 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 - is orders of magnitude larger than that for other ion complexes with citrate.

To obtain a more accurate estimate of the effect of citrate on Pu solubility in the event of human intrusion, calculations that use the Pu citrate formed inside a waste drum and model the mixing of that relatively concentrated brine with the average repository brines must be done, taking into account the time scales for mixing and the possibility that the intrusion event may release some brine from waste drums that has not had an opportunity to mix with the average repository brines.

The conclusion that EDTA complexes will not increase actinide solubility is probably correct, since the amount of EDTA is small and the Ni and Fe complexes have stability constants that are similar to those for the actinides. It is not shown, and is probably not true, that the more abundant citrate inventory will not increase actinide solubility, especially for Pu.

Specific comments:

(1) p.2 and later discussions of the same topic. The authors appear to believe that degradation of organic waste can only occur by microbial action and that the most detrimental product will be carbon dioxide gas. 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).

(2) p. 17 Figure caption seems to be incorrect. This should be the Castile Brine.

(3) p. 19 The corrosion equation at the bottom of the page is not balanced. If the corrosion is envisaged to occur through the action of water, rather than dissolved oxygen, it should be written as

$$Fe + 2H_2O = Fe(OH)_2 + H_2$$

(4) p. 20, near bottom "Therefore, radiolysis is not expected to affect the reduction-oxidation state of the repository." This is probably true on the scale of the entire repository, averaged over time; however, radiation effects within a waste canister that contains up to 10 g of ^{239}Pu could be quite significant on the local scale.

(5) p. 26 The selection of species for Th solubility includes $Th(SO_4)_2$ (aq.) and $Th(SO_4)_3^{=}$. The data base being prepared by OECD/NEA for recommended thermodynamic properties for Pu and Np includes sulfate complexes for Pu with one and two sulfate ligands and none with 3 sulfate ligands. In addition, the calculations of speciation with sulfate complexes for Th appear to give erratic results. See appendix B for further discussion.

(6) P. 29 The small range in uncertainties estimated for the calculation of solubilities seems to be at odds with the differences in calculated results for brines with rather similar chemistry and the difference between the calculated results and those measured for solubility of uranium dioxide in brines. See Appendix B for details.

(7) p. 35 bottom and 36 top. "Neretnieks (1982) has shown that when dissolved actinides in moving groundwater came in contact with Fe(II), the actinides were reduced to a much less soluble state and precipitated." Actually, Neretnieks did not show that reduction occurred; he did a model calculation that predicted the process should occur. His calculations, of course, have the same limitations concerning the adequacy of the data base used as do those done by Novak and Moore.

(8) p. 37, Table SOTERM-4. This table gives organic ligand inventories and calculated molal concentrations in a brine that is stated to be 29,841 m^3, being the smallest volume of brine that could escape from the repository. Converting to kg of brine using a density of 1.125 kg/L gives a total of 3.35×10^7 kg of brine. Using the inventory amounts in grams and converting to moles, one finds

Ligand	Mol. Wt.,g	Inventory, g	Inventory, moles
Acetate	60	1.3×10^6	2.2×10^4
Oxalate	126	1.6×10^6	1.3×10^4
Citrate	192	1.4×10^8	7.3×10^5
EDTA	372	2.3×10^4	62
(Mwt. as Versenate)			

Dividing the inventory in moles by the brine amount in kilograms gives the molal concentration of the organics. The table below compares the results of my calculation with the values given in Table SOTERM-4

Ligand	Molal conc. from Inventory calc. above	Molal conc. from SOTERM
Acetate	6.6×10^{-4}	5.2×10^{-4}
Oxalate	3.9×10^{-4}	2.3×10^{-4}
Citrate	2.2×10^{-2}	3.6×10^{-3}
EDTA	1.8×10^{-6}	2.0×10^{-6}

The differences in calculated concentrations range from 10% for EDTA to a factor of 6 for citrate.

References

J. E. Cross, F. T. Ewart, and B. F. Greenfield (1989) Modelling the behaviour of organic degradation products, Mat. Res. Soc. Symp. Proc. 127, W. Lutze and R. C. Ewing, eds., 715-722.

B. F. Greenfield, A. D. Moreton, M. W. Spindler, S. J. Williams, and D. R. Woodwar (1992) The effects of the degradation of organic materials in the near field of a radioactive waste repository, in Mat. Res. Soc. Symp. Proc. 257, C. G. Sombret ed., 299-306.

Appendix D: Summary of relevant articles used in preparation of this report

D. Rai, A. Felmy, D. A. Moore, and M. J. Mason (1995) The solubility of Th(IV) and U(IV) hydrous oxides in concentrated $NaHCO_3$ and Na_2CO_3 solutions, in Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 1143-1150.

Measurements of the solubility of U(IV) and Th(IV) in carbonate and bicarbonate solutions of various concentrations, in some cases with added NaOH. Both solubilites increase dramatically as carbonate concentrations increase beyond 0.1 M. In general, Th(IV) hydrous oxide was about 1000 times more soluble at a given carbonate concentration than U(IV). Solubilites of Th in Na_2CO_3 solutions decreased with added hydroxide ion at fixed carbonate concentration (1M).

U(IV) experiments were conducted in inert atmosphere (Ar chamber) and with Fe powder present in the experiments to ensure absence of U(VI). Th(IV) experiments were also conducted in an Ar atmosphere, but without Fe powder present. Solubility limits were approached from undersaturation by suspending freshly precipitated amorphous hydrous oxides in the appropriate solutions.

Th(IV) solubility increases from 10 E-8 M at 0.1 M Na_2CO_3 concentration to > 10 E-3 M at 1 M Na_2CO_3.   U(IV) shows the same behaviour, but the steep increase starts at 1 M Na_2CO_3 and finishes at 6 M. Species responsible for this increase is most likely $An(CO_3)_5^{6-}$.   Similar behavior is observed in bicarbonate solutions, but the increase in solubility begins at lower concentrations - 0.01 M for Th and about 0.08 M for U.

G. R. Choppin (1990) Actinide Speciation in Spent Fuel Leaching Studies, in Mat. Res. Soc. Symp. Proc. 176, V. M. Oversby and P. W. Brown, eds., 449-456.

Results from SKB's spent fuel testing program, in which LWR fuel is leached at room temperature in deionized water or in dilute sodium bicarbonate (synthetic) groundwater were used as the basis for deciding the expected speciation of U and Pu in these liquids under oxic conditions.

Figure 2 (p. 452) is a Pourbaix diagram for plutonium redox states under atmospheric CO_2 pressure and including carbonate complexes and hydrolysis reactions. The stable conditions shown are PuO_2^{2+}, PuO_2^{+}, and Pu^{4+} for oxic conditions and Pu^{4+} and Pu^{3+} for reducing conditions. It is noted that PuO_2^{+} disproportionates into PuO_2^{2+} and Pu^{4+} but that the rate of the reactions depends on the 4th power of the H^+ concentration and on the square of the PuO_2^{+} concentrations so that at low concentrations of Pu in neutral solutions the reaction rate is negligible. As an example of this lack of disproportionation, a table is given listing the redox state of Pu in natural waters and showing more than 50% Pu(V) in most cases. (Note that at high pH this would also be expected. This may explain the relative long life of Pu(V) in some of the speciation experiments done in brines.) Choppin concludes that in oxic conditions with Pu concentrations of 10^{-6} M and lower, the dominant species may be PuO_2^{+}.

The relative strengths of complexation for plutonium cations is $Pu^{4+} > PuO_2^{2+} > Pu^{3+} > PuO_2^{+}$, which is the same order of relative stability as for U cations. (Complexes of Pu(IV) are not discussed, since the paper limits itself to oxic conditons.)

Under oxic conditions, the spent fuel leaching studies showed apparent solubility for Pu of 5-10 ppb in DIW and 0.3 to 1 ppb in synthetic groundwater (0.002 M carbonate). The redox states present are interpreted to be Pu(V) as PuO_2^{+} and Pu(IV) as precipitated $Pu(OH)_4$ or $PuO_2 \cdot xH_2O$ present as the solid phase that limits total Pu solubility. The ratio of Pu(V) to Pu(IV) in the solution phase is predicted to be extremely large: 10^{23} in DIW and $10^{26.6}$ in the synthetic groundwater at pH 8.2. (Note: There is no reason to believe that this mechanism for solubility control under oxic conditions would not also work in brines.)

H. Nitsche (1991) Basic research for assessment of geologic nuclear waste repositories: what solubility and speciation studies of transuranium elements can tell us. Mat. Res. Soc. Symp. Proc. 212, T. Abrajano, jr. and L. H. Johnson, eds., 517-528.

Discusses experimental results for NpO_2^+, Pu^{4+}, and Am^{3+}/Nd^{3+} in J-13 well water, a natural dilute sodium bicarbonate groundwater, at pH 6, 7, and 8.5 and at T = 25, 60, and 90°C. The experimental results are compared to modelling calculations using EQ3/6. Tables of stability constants for solution species used in the calculations are given and may be useful for comparison with those used in calculations for WIPP.

Plutonium was added to the groundwater as Pu(IV). The solubility controlling species were found to be polymeric plutonium(IV) and lesser amounts of plutonium carbonates. At pH 7 and 8.5, Pu solubility at 25°C was about 5 x 10^{-7} M. The Pu used was Pu-239 isotope. Calculations that assumed crystalline PuO_2 predicted solubility at 25°C of 10^{-12} M. Use of amorphous $Pu(OH)_4$ in the calculations overestimated the solubility limit to be 10^{-4} M at 25°C. The oxidation state distribution found in the pH 8.5 experiments for species in solution was about 70% Pu(V) and 25% Pu(VI) with minor amounts of Pu(IV) and Pu(III)+polymer. (Note, this agrees with Choppin's predictions that the solid phase under oxic conditions contains Pu(IV), while the solution species would be Pu(V).)

J. E. Cross, F. T. Ewart, and B. F. Greenfield (1989) Modelling the behaviour of organic degradation products, Mat. Res. Soc. Symp. Proc. 127, W. Lutze and R. C. Ewing, eds., 715-722.

Research into the effect of alkaline degradation of organic materials that might be found in low and intermediate level radioactive wastes showed that the degradation of cellulose produced products that greatly increased the solubility of Pu. The details of the experimental results can be found in a report by J. D. Wilkins, UKAEA Report AERE R 12719 (1987).

The specific ligands responsible for the enhanced solubility could not be identified. Also, attempts to reproduce the effect using possible ligands with Pu did not produce as high a solubility. This shows the importance of examining actual waste mixtures to ensure that symbiotic effects are included.

Experiments were conducted with cement equilibrated with water with and without organic materials and with Pu added as a separate acid solution. The precipitated Pu was separated and the solution concentrations were measured. The results were

Cement alone + Pu	[Pu] = 5×10^{-10} M
Cellulose chemical degradation	[Pu] = 7×10^{-6} M
Cellulose, radiation degradation	[Pu] = 5×10^{-6} M

The effect of other organics was much less.

New experiments were done with separated organic acids. The closest results were found with D-saccharic acid $HOOC \cdot (CHOH)_4 \cdot COOH$, which at pH 12 gave Pu solubility of 7.2×10^{-6} M at 10^{-5} organic acid concentration, 7.3×10^{-6} M at 10^{-4} M organic acid, 8.2×10^{-6} M at 10^{-3} M organic acid, and 9.3×10^{-6} M at 10^{-2} M organic acid. This behaviour pattern, with little change in Pu solubility even though large changes were made in organic acid concentration, was successfully described so long as one considered complexation involving hydroxyl groups as well as carboxylic acid groups.

Both experiments and modelling were done for conditions at a redox potential of + 200 mV.

B. F. Greenfield, A. D. Moreton, M. W. Spindler, S. J. Williams, and D. R. Woodwar (1992) The effects of the degradation of organic materials in the near field of a radioactive waste repository, in Mat. Res. Soc. Symp. Proc. 257, C. G. Sombret ed., 299-306.

A number of different solid organic materials were degraded in the presence of Portland cement and blast furnace slag (representing the concrete components in the proposed UK Nirex low and intermediate level radioactive waste repository) at 80°C under anaerobic conditions. Generally the experiments contained 10% organic and 90% cement. Samples of liquid were taken periodically, cooled to room temperature, pH adjusted to 12 (if necessary), and then spiked with a small volume of radioactive elements in acid solution to measure their solubility in the leachates. After 2 days samples were taken and filtered, and then the radioelement concentrations were measured.

Results found for Pu(IV) solubility in leachates produced from 500 days of degradation of the organics were

Cellulose or wood fiber	10 E-3 M
Cotton wool	10 E-5 M
Bakelite	6 x 10 E-6 M
PVC	10 E-9 M
Polystyrene	5 x 10 E-10 M
Nylon, Polythene, and	
Pure cement leachate	10 E-10 M

Degradation of cellulose under aerobic conditions resulted in a lower solubility for Pu(IV), namely 10 E-4 M, and solubilities of 10 E-5 M for Th(IV) and U(IV). Am(III) and Np(IV) in these leachates had apparent solubilities of 10 E-6 M.

The effect of varying cellulose to cement ratio was tested under anaerobic degradation conditions. The Pu (IV) solubilites found were 4 x 10 E-10 M at 0.1% cellulose, 4 x 10 E-9 M at 0.5% cellulose, but 1 x 10 E-6 M at 1% cellulose.

The product of cellulose degradation that is most likely to explain the enhanced Pu solubility is isosaccharinic acid (ISA); other possible degradation products are produced in lesser amounts and have less effect on Pu solubility than ISA. If ISA is exposed to cement, it will sorb onto the cement surface, thus diminishing its effect on Pu solubility. This is thought to explain the results found at low cellulose loadings in cement.

Modelling calculations were able to reproduce the effects seen in the experiments. It was concluded that the solubility enhancement for Pu was achieved through complexation that involved 4 deprotonated hydroxyl groups in the bonding.

I. AlMahamid, K. A. Becraft, N. L. Hakem, R. C. Gatti, and H. Nitsche (1996) Stability of various plutonium valence states in the presence of NTA and EDTA, Radiochimica Acta 74, 129-134.

Experiments were conducted using solutions of nitrilotriacetic acid (NTA) and ethylenediaminetetraacetic acid (EDTA) with all four soluble plutonium oxidation states - III, IV, V, and VI - at macroscopic (10^{-3}M) and microscopic (10^{-7}M) concentrations. Experiments were performed at room temperature in an argon atmosphere. Pu was prepared by dissolving PuO_2 electrochemically in 1 M $HClO_4$ and then adjusting to produce the desired oxidation states.

NTA was added to an acidic solution of Pu and the pH adjusted to 5 with NaOH. Final ionic strength of the solutions was about 0.01 M. At the higher Pu concentrations, the final species is a Pu(IV)-NTA complex, regardless of the initial oxidation state of the Pu, at NTA/Pu ratios of 6. At higher NTA amounts, the Pu(IV) polymeric form can even be dissolved. With EDTA, only Pu(III) was studied. This oxidized to produce an EDTA-Pu(IV) complex.

Studies with the lower Pu concentrations with NTA resulted in mainly Pu(IV) if the starting valence was III or IV. For initial Pu(V), about 65% of the Pu persisted as V, with a little becoming VI and most of the rest present as IV. For initial Pu(VI) at NTA/Pu of 100, 48% of the Pu was IV after 10 days and 31% was V, with 21% remaining as VI. Very high NTA/Pu ratios reduced essentially all of the Pu(VI), producing 38% Pu(IV) and 61% Pu(V). Experiments with EDTA at ligand to Pu ratios of 100 and of 1 also showed persistance of Pu(V) if the starting materials were VI or V, but little or no Pu(VI). It is expected that the Pu(V) will reduce to Pu(IV) with time. These solutions had low ionic strength (as low as 10^{-5} M) and no active reducing agents other than the organic ligands themselves.

J. DePablo, J. Giménez, M. E. Torrero, and I. Casa (1995) Mechanism of unirradiated UO_2 (s) dissolution in NaCl and $MgCl_2$ brines at 25°C, Mat. Res. Soc. Symp. Proc. 353, T. Murakami and R. C. Ewing, eds., 609-615.

Experiments using unirradiated crystalline UO_2 (s) with 1 mm particle size and BET surface area of 0.0016 m^2/g were done in synthetic brines. Both oxidizing and reducing conditions were studied. Reducing conditions were maintained using a hydrogen flux and a Pd catalyst.

Brine compositions: molal concentrations

Species	NaCl-brine	$MgCl_2$-brine
Na+	6.036	0.48
K+	0.037	0.57
Mg^{2+}	0.018	4.21
Ca^{2+}	0.021	0
Cl-	6.036	8.84
$SO_4^=$	0.058	0.32
Ionic Str.	6.25	14.00
pH	7.7	4.7

The UO_2 (s) had an initial surface condition that was very oxidized, $UO_{2.7}$ as measured by XPS. This led to an initial rapid dissolution of the oxidized surface even when the solution was maintained with reducing conditions. The solution concentrations in both brines gradually decreased and settled after 20 to 25 days at steady-state values of 2.8 x 10^{-7} mol/kg in the NaCl brine and 3.1 x 10^{-7} mol/kg in the $MgCl_2$-brine. At the end of the experiments the Eh was measured to be 0 to 60 mV (compatible with the stability of UO_2) and the surface of the dissolving solid was measured to have a composition of $UO_{2.1}$ as measured by XPS. A model calculation was made using the PHRQPITZ code (the PHREEQ equilibrium code with Pitzer parameters added) and gave quite good agreement of the predicted concentrations with those measured in the experiments. The predicted concentrations at zero ionic strength were about a factor of 3 lower than those predicted for the brines.

Under oxidizing conditions, the final uranium concentration in the $MgCl_2$-brine was about 10 E-5.7, and still slowly rising, while that in NaCl brine was considerably lower (10 E-6.4) and was constant. Modeling calculations for oxidizing conditions overestimated the solubility of U in the Mg-brine by about a factor of 1000, while modeling of the NaCl brines was able to produce compatible results by using a schoepite solubility of 6.2 x 10^{-7} mol/kg as the solid controlling the final solution concentrations.

E. Östhols, J. Bruno, and I. Grenthe (1994) On the influence of carbonate on mineral dissolution: III. The solubility of microcrystalline ThO_2 in CO_2-H_2O media, Geochim. Cosmochim. Acta 58, 613-623.

The solubility of microcrystalline ThO_2 was measured in 0.5M $NaClO_4$ at 25°C and 1 atm. as a function of pH and partial pressure of CO_2 to determine the stability of carbonate complexes of Th^{4+}. The following species and stability constants were proposed to explain the results:

For 0.5 M $NaClO_4$ conditions,

(1) $ThO_2(act) + 4H^+ \leftrightarrow Th^{4+} + 2\ H_2O$ $\log K_s = 9.37 \pm 0.13$

(2) $ThO_2(act) + H^+ + H_2O + CO_3^{2-} \leftrightarrow Th(OH)_3CO_3^-$ $\log \beta_{1,3,1} = 6.11 \pm 0.19$

(3) $ThO_2(act) + 4H^+ + 5CO_3^{2-} \leftrightarrow Th(CO_3)_5^{6-}$ $\log \beta_{1,0,5} = 42.12 \pm 0.32$

Note: For mass balance, equation (3) should have 2 H_2O added to the right hand side. This will not affect the calculated $\log \beta_{1,0,5}$.

Extrapolation of these constants to zero ionic strength gave

(1) $\log K_s = 7.31 \pm 0.3$

(2) $\log \beta_{1,3,1} = 6.78 \pm 0.3$

(3) $\log \beta_{1,0,5} = 39.64 \pm 0.4$

The solid used in these experiments was a freshly prepared precipitate of thorium oxide/hydroxide, which was of low crystallinity, and the atmospheres were mixtures of 97% CO_2 in N_2, 10% CO_2 in N_2, and pure N_2.

For the experiments at 0.1 atm carbon dioxide, the crossover between the Th-hydroxycarbonate and Th-pentacarbonate species as dominant in solution occurred at pH = 7.5. Above pH 8, essentially all of the dissolved Th was present as the pentacarbonate complex.

F. L. Sayles and W. S. Fyfe (1973) The crystallization of magnesite from aqueous solution, Geochim. Cosmochim. Acta 37, 87-99.

In the introduction section of this paper, evidence is presented to show that the oceans are supersaturated with respect to magnesite and dolomite, and that their formation is controlled by kinetic rather than thermodynamic considerations. Natural occurences of magnesite are generally in hypersaline environments, with salinity much greater than seawater.

Reagent grade basic magnesium carbonate (hydromagnesite) was reacted with saline solutions that had been equilibrated with atmospheric pressure carbon dioxide at 25°C. The solid and solutions were sealed into Pyrex ampules and reacted at 126°C to produce magnesite, which was detected using X-ray diffraction. The experiments showed that there was a long induction period prior to the production of any detectable magnesite. After crystallization of magnesite started, conversion to pure product proceeded fairly rapidly. The conversion rate increased with ionic strength and partial pressure of carbon dioxide, but decreased with Mg concentration. Nucleation of magnesite occurred on hydromagnesite surfaces (seen in SEM images).

M. P. Neu, D. C. Hoffman, K. E. Roberts, H. Nitsche, and R. J. Silva (1994) Comparison of chemical extractions and laser photoacoustic spectroscopy for the determination of plutonium species in near-neutral carbonate solutions, Radiochimica Acta 66/67, 251-8.

Experiments were conducted to investigate the solubility and speciation of ^{242}Pu in a 1.93 mM total carbonate solution of 0.100M $NaClO_4$ at pH = 6.0 and 30°C. The isotope ^{242}Pu was chosen to minimize the radiolysis effects that occur. The experiments were conducted in a controlled atmosphere argon glove box in which the oxygen concentration was typically 18 to 30 ppm. The Pu solution was added to a 0.100M $NaClO_4$ solution that had been pre-equilibrated with 5.71% CO_2 in Ar gas together with an amount of base needed to neutralize the acid from the Pu stock solution.

Experiments with a starting solution of Pu(V) with an initial concentration of 2.51×10^{-5} M had a soluble Pu concentration of $2.1 \pm 1 \times 10^{-5}$ M after 53 days. The speciation was determined by spectroscopy to be PuO_2^+ at the level of 95 ± 5%. When the Pu solution was initially Pu(VI) as PuO_2^{2+} at $2.4 \pm 1 \times 10^{-4}$ M, the concentration of soluble Pu after 120 days was $3.1 \pm 5 \times 10^{-6}$ M, or only 1.3% of the initial concentration. This was also 7 times lower than the final concentration when Pu(V) was the initial valence state for the Pu, even though it is Pu(V) as PuO_2^+ that represents the soluble Pu after 28 days of the experiment. If Pu(VI) disproportionates to produce Pu(IV) at pH =6, polymeric Pu-hydroxide will precipitate. This may explain the lower final concentrations found when Pu(VI) was the starting valence.

Speciation inferred from chemical extraction agreed with that measured directly from spectroscopy.

H. Nitsche, K. Roberts, R. Xi, T. Prussin, K. Becraft, I. Al Mahamid, H. B. Silber, S. A. Carpenter, R. C. Gatti, and C. F. Novak (1994) Long term plutonium solubility and speciation studies in a synthetic brine, Radiochimica Acta 66/67, 3-8.

This paper describes solubility studies of ^{239}Pu in a synthetic brine (H-17) conducted with a gas phase overpressure of 0.26% CO_2 and 20.75% O_2 in argon. Five separate experiments were conducted using initial species of Pu as Pu^{3+}, Pu^{4+}, PuO_2^{+}, PuO_2^{2+}, and Pu(IV) polymer at concentrations high enough to ensure supersaturation. The brine composition was

Ca^{2+}	0.029 M/L	Cl^{-}	2.482 M/L
Mg^{2+}	0.074	$SO_4^{=}$	0.075
Na^{+}	2.397	Br^{-}	0.00095
K^{+}	0.031	TIC	0.00082 (Total inorganic C as HCO_3)
B^{3+}	0.004		

pH = 7.0, $pCO_{2(g)}$ = 10 E-2.56 ATM
Ionic strength = 3.0 molal
Density = 1.10 g/cm^3

This brine is similar chemically to the Castile simulant brine ERDA-6 diluted by a factor of 2.

Solids that precipitated from the samples that originally contained Pu(III), Pu(IV) or Pu(IV) polymer appeared to be identical and consist of Pu(IV) polymer. Solids recovered from the experiments that initially contained Pu(V) and Pu(VI) effervesced when dissolved in HCl, indicating that they contained carbonate. Similarities of the x-ray patterns for these solids with those of $KPuO_2CO_3$(s) suggested that the solid was $NaPuO_2CO_3$(s), for which no reference powder pattern was found, since there is so much more Na than K in the brine.

Steady state concentrations found range from 2 x 10^{-7} M for solutions that originally contained soluble Pu(III) and Pu(IV), to 3.6 ± 0.8 x 10^{-7} M for Pu(V) solution, and 7.6 ± 2.3 x 10^{-7} M for initial Pu(VI). The predominant oxidation state of the solution species at the end of the experiments was (VI) with lesser amounts of (V), found mainly in those experiments that began with Pu as VI and V. Eh measured in solution at the end of the experiments was +400 to +500 mV vs. the normal hydrogen electrode.

D. T. Reed, S. Okajima, and M. K. Richmann (1994) Stability of plutonium (VI) in selected WIPP brines, Radiochimica Acta 66/67, 105-111.

States that the predominant actinide in TRU waste will be plutonium-239 at the level of up to 10 grams per waste drum.

Studies were done in two synthetic brines - brine A (similar to Salado conditions) and ERDA-6, which represents expected conditions in the Castile formation brines - and in two brines collected from the WIPP site. The natural brines had a composition that was between those of the synthetic brines with the exception of sulfate, which was a factor of two higher than ERDA brine for one of the natural brines. The pH was about 6 in all cases.

Pu(VI) was stable in Brine A, which contained carbonate. In the ERDA brine, which had no intrinsic carbonate (other than that which would dissolve from contact with normal air), the predominant species was a Pu(VI) hydrolytic form, with the possibility of some Pu(V) forming over time. In the natural brines, the Pu(VI) species disappeared from spectra after 6 days and no peak attributable to Pu(V) was observed. Final concentrations in these brines for Pu were about 5×10^{-5}M, which would make direct observation of Pu(V) doubtful; however, the authors conclude that the Pu has been reduced further to an unidentified species, possibly polymeric plutonium.

8.4b Solubility Issues Raised by Dr. Rodney C. Ewing After the February 20, 1998 Meeting Between the EEG and Sandia.

Department of Nuclear Engineering and Radiological Sciences
The University of Michigan
Ann Arbor, Michigan 48109-2104
phone: (734) 647 8529
fax: (734) 647 8531

Rodney C. Ewing

February 22, 1998

Robert H. Neill, Director
Environmental Evaluation Group
Suite F-2, 7007 Wyoming Boulevard, NE
Albuquerque, New Mexico 87109

Dear Bob,

Thank you for inviting me to attend the technical exchange meeting between DOE contractors and the EEG on the subject of the actinide source term (AST) held this past February 20th. Since the time of the last meeting of the National Research Council's Committee on the Waste Isolation Pilot Plant (May, 1997), I have not had the opportunity to follow the progress of the AST program. I should also emphasize that I am no longer on the NRC WIPP Committee, and these brief comments represent my own views. I am not a representative or consultant for any committee or agency regarding the WIPP.

I want to emphasize my view of the importance of the actinide source term work. Although the NAS (1996) report on WIPP arrived at a positive evaluation of the potential for the WIPP as a repository for transuranic waste, the same report clearly identified outstanding technical issues, prominent among them was the issue of actinide solubilites in brine (page 5). Unfortunately, there was little of substance to review concerning the AST program at the time the WIPP committee completed its report in October of 1996. We concluded (page 62):

> "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."

Thus, I believe the review of this topic by EEG and EPA is essential to establishing confidence in the data and models used for the AST in the performance assessment. I note that the most recent PA analysis suggests that the actinide solubilities in brine are of lesser importance; however, this conclusion is based on the new and revised view of transport in the Culebra and the introduction of the MgO backfill. In the event, either or both of these issues change with further analysis or experimental results, then the role of actinide solubilities may again become important.

My general observations and comments include:

1. The oxidation state analogy and the FMT calculations appear to predict trends in actinide solubilities; however, this work still requires important experimental verification. The NAS (1996) report concluded (page 63),

   "Although some aspects of its geochemical behavior can be estimated by studies of other actinides using the oxidation state model, ideally, data for each oxidation state should be followed by experiments with plutonium."

   The presentations this past week only emphasized and confirmed the need for such experiments. Particularly important were the points made by the EEG consultant, Dr. Virginia Oversby, which were based on a critical review and use of data in the published scientific literature. It seems to me that the credibility of the project would be greatly enhanced by the comparison of FMT results to experimental results obtained outside of the project, as an example, studies of actinide solubilities in spent fuel or UO_2 corrosion experiments.

2. It certainly appears to be an opportune time to review the results and analysis of the source term test program (STTP) at LANL. The limited results presented, were used to conclude that the predicted actinide concentrations in brine are "conservative". In my view, the data only suggest that there are processes (not identified) that affect the actinide concentrations, and these processes, in general, lower the actinide concentrations.

   There was some mention of discontinuing some of these tests; however, considering the time, effort and expense required to begin and sustain these experiments, such a decision should be made only after careful review and analysis of the data from the STTP experiments. Although some of the experiments may have no present applicability to the WIPP project, DOE may want to consider the experiments in a wider context, as an example the interaction of actinides and clays may be important to other DOE projects; thus, there may be value to continuing even those experiments which are not now considered to be relevant to WIPP.

3. The project still is not in a position to present and discuss models of the longer term evolution of the chemistry of the WIPP system. In this regard, well constrained, simple, experiments with relevant actinides (e.g., Pu) that are designed to run for years are still much needed. I see no reason that such experiments cannot be initiated and run through the operational phase of the repository, and their results may be utilized in the recertification process. This is consistent with the recommendations of the NAS (1996) study (page 64). Similar experiments to study retardation in the Culebra would also be of value.

4. Concerning the report and comments by the EEG consultant, Dr. V. Oversby, I believe that some of the issues she raised can be rather directly addressed by the exchange of recent and relevant results, straightforward calculations, and/or limited additional experimental work. However, her approach to the review of the CCA, particularly in the areas of verification and validation, merit careful attention. I believe that she very commendably demonstrated the real meaning of a *critical* review by:

   i.) comparison of project results to the published literature (e.g., use of the NEA data base; UO_2 and spent fuel corrosion studies);

   ii.) comparison of results from project codes and models to more generally used and accepted geochemical code results.

I hope that these brief comments are of use to the project. You may give copies to this letter to DOE and EPA.

Sincerely,

Rod Ewing

cc: John Garrick, chair, NRC WIPP Committee
Thomas Kiess, staff officer, NRC WIPP Committee

8.4c Solubility Issues Raised by Dr. Virginia Oversby After the February 20, 1998 Meeting Between the EEG and Sandia.

Issues related to solubility of Pu at WIPP

1) Heterogeneous vs homogeneous equilibria

Calculations of solubility of actinides under WIPP conditions have been done assuming that before any release the repository will contain 29,841 cubic meters of brine that is well equilibrated. This assumption is doubtful and other models should be investigated to determine the effects of local variations in brine compositions and actinide speciation and concentration. After closure, the repository salt formation will creep and close up void spaces. Subsequent intrusion of brine, either as drilling fluid during an intrusion event or as intrusion of pressurized brine following penetration to layers below the repository, will add concentrated - if not saturated - brine solutions to the repository horizon. After fluid is added, the resulting physical state of the repository should still be one of rather low total porosity and have a high proportion of solids relative to fluids. In that case, equilibration of fluid compositions over large distances is unlikely, since the mechanism of mixing would be diffusion rather than advection. Local pockets of solutions with chemical compositions representative of the range of potential waste container soluble actinide inventory should be considered, rather than the grand average of the actinide inventory and brine compositions. This is particularly important for issues such as the complexation of Pu by citrate and/or cellulose degradation products, as well as the changes in solubility that may accompany presence of different alteration products of MgO.

2) MgO alteration products

The CCA calculations of solubility of actinides assumed that MgO backfill would alter to produce an equilibrium assemblage of brucite and magnesite. Later investigations indicated that the first phase formed from reaction of MgO with aqueous carbon dioxide dissolved in the brine would be nesquehonite. Calculations of actinide solubility in the presence of nesquehonite resulted in estimates of Th solubility (and, thus, other actinide (IV) elements) that were in the range of those calculated for the case without backfill. While it was argued that the longer-term phase would be hydromagnesite, nesquehonite might persist for rather long times.

At the meeting between WIPP staff and EEG on February 20, 1998, it was stated that the reason nesqhehonite had been found in the previously reported experiments was that a high pressure of carbon dioxide had been used. New experiments, with lower carbon dioxide pressure, produced an unidentified phase, persistent over at least 200 days, that was thought to be hydromagnesite.

Two issues remain to be resolved: 1) what is the identity of the phase in the new experiments, and 2) what is the effect of heterogeneous repository conditions on the pressure of carbon dioxide in local regions of the repository. Gas generation rates will depend on the local abundance of bacteria and microbes as well as the local abundance of materials that can degrade to produce carbon dioxide. An analysis of maximum gas generation rates in local areas is needed before it can be assumed that nesquehonite can not form.

3) Relative solubility of Th versus other actinides

As part of the rationale for using Th as an analog to estimate the solubility of other actinides in the (IV) oxidation state, the WIPP staff claim that Th always shows higher solubility than U(IV) and Pu(IV). While this has been shown to be the case for freshly precipitated Th and U hydroxides, it is not the case for the vast majority of materials that contain U and Th in natural settings - i.e., minerals containing U and Th. A vast body of geochemical data pertaining to the U-238 decay series shows that U leaches from minerals in preference to Th.

Th (and Pu) forms an amorphous solid when freshly prepared from solution by precipitation of the hydrous oxide. The solubility of this amorphous hydrous oxide can be quite high. With time, Th and Pu precipitates of hydrous oxides age into materials that have increasing degrees of crystallinity. As crystallinity increases, the measured solubility of the materials decreases. This is the major reason for the very large range of reported solubility data for Th and Pu oxides in the literature.

4) Solution speciation in solubility calculations

In order to evaluate the potential validity of calculated actinide solubilities one must closely inspect the identity of the solid phases assumed to control the brine composition and the speciation of the actinides in solution. As conditions change (e.g., identity of solids assumed to be present, or chemistry of the brine), the speciation of the actinides should change in a manner consistent with the changes in assumed solids and fluid compositions. Changes in speciation between two successive calculation that cannot be explained by rational chemical arguments are symptomatic of problems in the chemical data base or the calculational methods. An example of this type of problem was seen in the CCA calculations, where Th solubility was dominated by di- and tri-sulfate complexes in the no backfill case, but these species were calculated to be insignificant in the case where Mg was added. Detailed examination of the solution speciation did not indicate any reason for this drastic change in calculated speciation.

5) Calculations and measurements for pyrochemical salts

Tests underway at LANL using actual waste samples have produced conditions for which the calculated solution concentrations for Pu were greater than 0.001 M. The details of these calculations have not been presented. If the pH of the brines in contact with the pyrochemical salts is near neutral or higher, the high calculated solubility should not be greatly affected by the assumption of adding MgO to the system. Measurements of Pu-239 in these tests gave concentrations of about 1 E-5, which is higher than the concentration used in the CCA for demonstration of compliance with release limits. These high calculated and measured solubilities need to be investigated, particularly in light of the fact that inventories of Pu contained in chloride salts at Rocky Flats exceed 1 ton.

6) Direct estimates of solubility for U(IV) and Pu(IV)

The Nuclear Energy Agency (NEA) of the OECD has published a compendium of recommended values for the thermodynamic properties of U. Data from this volume (I. Grenthe, ed.) should be used to provide a direct estimate of the solubility of U(IV) in brines similar to those expected at WIPP. Also, data on U solubility in brines published in the open literature should be used as a means to estimate solubilities for U(IV) under WIPP conditions.

The NEA is also preparing a compendium of recommended values for the thermodynamic properties of Np and Pu (R. Lemire, ed.). This volume is in the final stages of preparation, so that any changes in the recommended data between the present draft and the final issued volume should be small. This volume could provide a sound basis for estimation of Pu solubility in WIPP brines.

7) Needs for additional experimental work

Direct measurements of solubilities of actinides under conditions that are assumed to be relevant for WIPP are needed. Some examples of the types of experiments needed are measurements of the solubility of Pu in brines in the presence of Fe, direct measurement of Pu speciation in brines, and solubility of actinides in the presence of the alteration phases of MgO, both at low and high carbon dioxide concentrations.

8.5 WIPP Related Geological Issues (Chaturvedi, 1993)

WIPP-RELATED GEOLOGICAL ISSUES

LOKESH CHATURVEDI
New Mexico Environmental Evaluation Group, 7007 Wyoming Boulevard NE, Suite F-2, Albuquerque, New Mexico 87109

Abstract—The Waste Isolation Pilot Plant (WIPP) is a proposed repository for disposal of defense transuranic (TRU) radioactive waste. Located in southeastern New Mexico, 25 mi (40 km) east of Carlsbad, the repository has been excavated in the Salado Formation bedded salt at a depth of 2150 ft (655 m) below the surface. The concept of geologic isolation of radioactive waste, with the half-life of the radionuclides measured in tens of thousands of years, is to primarily rely on the geologic barriers to keep the radionuclides from leaking to the biosphere. Several geologic features and processes have been identified during the site characterization of the WIPP site that could impact the performance of the repository for the 10,000 year regulatory period. These include salt dissolution, breccia chimneys, brine reservoirs, Salado Formation hydrology, hydrology of the overlying Rustler Formation water-bearing units, disturbed rock behavior and natural resources. These geologic factors are being considered in the analysis of breach scenarios from the WIPP repository for the next 10,000-year period.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is being excavated and constructed to be a geologic repository for permanent disposal of defense transuranic (TRU) waste. It is located 25 mi (40 km) east of Carlsbad, New Mexico. In addition to support facilities on the surface to provide office space to workers and to receive and handle radioactive waste (Fig. 1), there are four shafts (waste handling, construction and salt handling, air intake and air exhaust shafts) that connect the surface to the underground facilities. The project is being administered by the U.S. Department of Energy (DOE), with Sandia National Laboratories

FIGURE 1. An aerial view of the WIPP (courtesy U.S. Department of Energy).

in charge of site characterization and most of the experiments and Westinghouse Electric Corporation as the managing contractors.

The repository is excavated at a depth of 2150 ft (655 m) below the surface and consists of an experimental area to the north and the main repository to the south of the shafts (Fig. 2). The experiments carried out in the northern part of the facility include mechanics of closure of excavations; effect of heat on closure and brine migration; development of plugs and seals to be used to plug the excavations, shafts and bore holes; and the effect of salt creep on the waste drums. The repository itself will consist of 56 "rooms," each 300 ft long, 33 ft wide and 13 ft high (91.5 m × 10 m × 4 m), divided in eight panels of seven rooms each. The seven rooms of the first panel were excavated between 1986 and 1988, since the DOE had planned to start shipping radioactive waste to WIPP in 1988 for an "operational demonstration." Excavation for the other seven panels of the repository has not yet begun.

Transuranic waste consists of various kinds of trash including paper, rubber, wood, metals and sludges, contaminated with radionuclides heavier than uranium with half-lives greater than 20 years and a level of contamination exceeding 100 nanocuries per gram. The waste has resulted as a by product of nuclear weapons production in the United States during the past 50 years. Only waste retrievably stored since 1970 is presently planned to be shipped to WIPP. Two-thirds of the planned capacity of waste for WIPP is yet to be produced. Two categories of the TRU waste are currently stored at DOE-managed national laboratories and will be disposed at WIPP. The contact-handled (CH-TRU) waste is contained in 55 gallon (0.21 m³) mild carbon-steel drums that have a maximum surface-dose rate of 200 millirem per hour. The remote-handled (RH-TRU) waste will be disposed of in 0.85 m³ capacity cylindrical canisters with unshielded surface dose rate higher than 200 millirem per hour and up to a maximum of 1000 rem per hour. The 50 hectare WIPP repository has been designed to hold 850,000 drums (176,000 m³) of CH-TRU waste containing 9 million curies of radioactivity and 7,500 canisters (7100 m³) of RH-TRU waste containing 5 million curies. The CH-TRU waste drums will be stacked three high in 56 "rooms" to be excavated in salt. The RH-TRU canisters will be disposed in 36 in. (0.91 m) diameter and 10 ft (3 m) deep horizontal holes.

The TRU waste to be disposed at WIPP consists of both hazardous chemical waste and radionuclides. Its disposal should therefore be according to the requirements of the Environmental Protection Agency (EPA) Standards for the handling and permanent disposal of transuranic radioactive materials (U.S. CFR, 1985), as well as the requirements of the Resource Conservation and Recovery Act (RCRA) (U.S. CFR, 1991). The idea of permanent disposal of the radioactive waste is to isolate it from the environment for a very long period of time. The EPA Standards for radiation protection specify a time of 10,000 years for containment of the waste and require probabilistic risk analyses to assure that potential releases to the environment will have a low probability and not allow more than a specified amount of various radionuclides. The RCRA regulations require assurance of no releases of hazardous materials beyond a specified "unit boundary," which in the case of WIPP has been accepted to be the 2.5 mi by 2.5 mi (4 km × 4 km) WIPP site laterally and up to the top of the Salado Formation vertically.

A geological repository relies primarily on the geology of the site to provide containment of waste for thousands of years. This is especially true for the WIPP project, because there is no commitment to use robust engineered barriers for disposal of the TRU waste. Ninety seven percent (by volume) of the waste to be disposed at WIPP will be contained in ordinary mild carbon steel 55 gallon drums with an expected life of only 20 years, or in Standard Waste Boxes made of plywood or metal. The containers are expected to get crushed and corroded in a few years in the corrosive briny environment of a repository in salt beds and salt creep is expected to close the openings and form a cocoon around the waste. Geologic integrity and the absence of geologic and geohydrologic conditions or processes that may breach the integrity of the repository are, therefore, critical issues in assessing the suitability of the WIPP site for use as a permanent geologic repository for radioactive waste.

The purpose of this paper is to describe and discuss the geological features and processes that potentially may have an impact on the integrity of the WIPP site. Most of the geologic and hydrogeologic investigations pertinent to the WIPP have been performed by the scientists of the U.S. Geological Survey, Sandia National Laboratories, other contractors of the DOE and university researchers. The Environmental Evaluation Group (EEG) has analyzed the importance of various geologic issues and controversies as they have come to light from time to time and has proposed mechanisms and further investigations to resolve them. The EEG is affiliated with the New Mexico Institute of Mining and Technology and has offices in Albuquerque and Carlsbad. It was established in 1978 as an interdisciplinary group of scientists and engineers to provide an independent technical evaluation of various aspects of the WIPP project to protect the health and safety of the people of New Mexico. The group is funded 100% by the DOE.

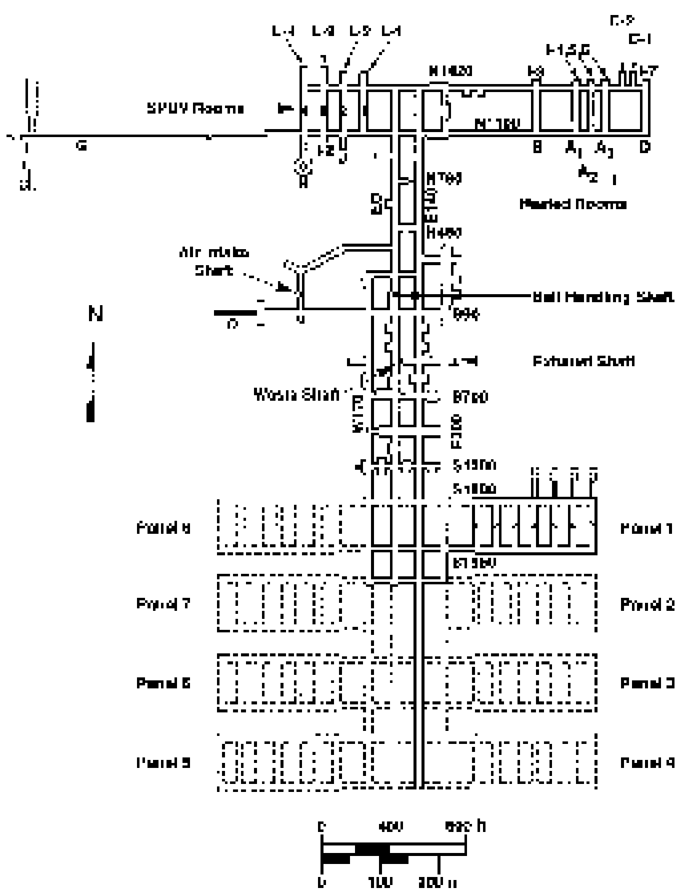


FIGURE 2. Underground layout of the WIPP repository.

GEOLOGICAL SETTING OF WIPP

The WIPP site is situated in the northern part of the Permian Delaware Basin. The repository is located at a depth of 2150 ft (655 m) from the surface in the Salado Formation of the Permian Ochoan Series. The Salado Formation is about 1975 ft (602 m) thick at the center of the WIPP site and the repository is situated at a depth of 1300 ft (396 m) from the top of the formation (Fig. 3). The Delaware Basin is bounded by the Permian Capitan Reef (Fig. 4). The basin contains about 15,000 ft (4575 m) of Paleozoic sedimentary rocks overlying the Precambrian basement. The formations of interest with respect to the WIPP project, from the oldest to the youngest, are the Bell Canyon Formation of the Delaware Mountain Group, the Castile, Salado, Rustler and Dewey Lake Formations of the Permian Ochoan Series, the Upper Triassic Santa Rosa Sandstone Formation that tapers from the east to the west across the WIPP site and the Pleistocene Gatuña Formation. A caliche layer known as the Mescalero caliche is consistently encountered underlying the surficial sands at the WIPP site.

The site lies on a generally flat plain covered with sand, caliche and

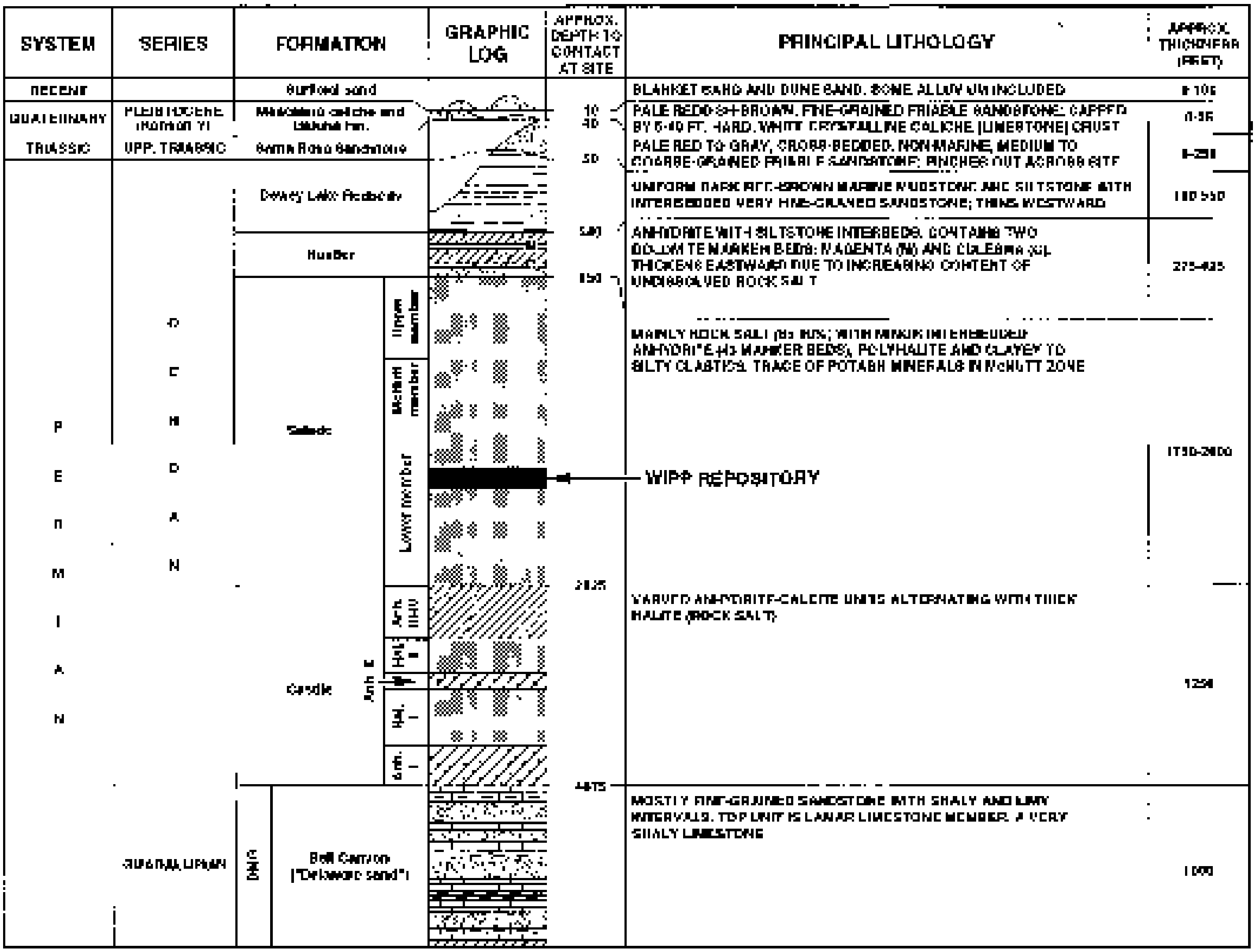


FIGURE 3. Generalized stratigraphy at the WIPP site, including the complete Ochoan section and overlying strata, plus underlying Guadalupian Bell Canyon Formation (adapted from Fig. 4.3-2 of Powers et al., 1978).

desert bushes. It is located in a gypsum karst region. A subsidence landform feature called Nash Draw lies about 3 mi (5 km) west of the WIPP site. It is 6–7 mi (10–12 km) wide in the east-west direction, about 18 mi (30 km) long in the north-south direction and has resulted from erosion by solution and fill (Lee, 1925) of soluble rocks, a process that has occurred in the past and which is also presently active. The Pecos River flows from northwest to southeast, about 12 mi (20 km) west of the WIPP. Based on the presence of saline seeps along the Malaga Bend of the Pecos River (14 mi southwest of WIPP repository), a marked increase in the salinity of the river south of the bend and the general flow direction of the water-bearing beds of the Rustler Formation, the Malaga Bend has been identified as an area of discharge of the Rustler water from Nash Draw and perhaps even from the WIPP site.

All the formations shown on Fig. 3 are geohydrologically significant. Ground water occurs in the upper part of the Bell Canyon Formation in poorly cemented sandstone stringers (Hiss, 1976). The Castile Formation is about 1500 ft (470 m) thick at the WIPP site and overlies the Bell Canyon. It consists of alternating layers of anhydrite and halite, with four anhydrite and three halite members. The uppermost anhydrite member contains pressurized brine reservoirs that have been encountered by two of the boreholes drilled for the WIPP project and by several oil and gas exploratory wells. The Salado Formation overlies the Castile Formation and the repository is located in its lower part (Fig. 3). The Salado consists primarily of halite with a zone of potassium- and magnesium-bearing minerals (sylvite, langbeinite) and thin (<3 ft) seams of clay, anhydrite and polyhalite. Before 1986, thick salt beds, as in the Salado Formation, were considered essentially dry and impermeable. Observations from the WIPP excavations, however, indicate that the salt beds may be saturated with brine and the salt may exhibit Darcian flow, albeit at very low permeability.

The Rustler Formation overlies the Salado and contains the most important geohydrologic units in the region. The thickness of the Rustler varies between 275 ft to 425 ft (84 m to 130 m) in the northern Delaware Basin and is approximately 310 ft (95 m) at the WIPP site. Sedimentology of the Rustler Formation was described by Lowenstein (1987) and Powers and Holt (1990). The formation contains three recognized fluid-bearing zones: in ascending order the Rustler-Salado contact residuum, the Culebra dolomite and the Magenta dolomite. The transmissivity of the Culebra is the highest, followed by the Magenta and the Rustler-Salado contact. The water quality is highly variable within each unit. The total dissolved solids concentration is lowest in the Magenta and highest in the Rustler-Salado contact zone. Nearly all the water in the Rustler Formation at the WIPP site has total dissolved solid (TDS) concentrations greater than 10,000 mg/l.

All three Rustler hydrologic units probably discharge into the Pecos River, 14 mi (22 km) to the southwest near the Malaga Bend. The recharge areas are identified rather imprecisely as being upgradient of

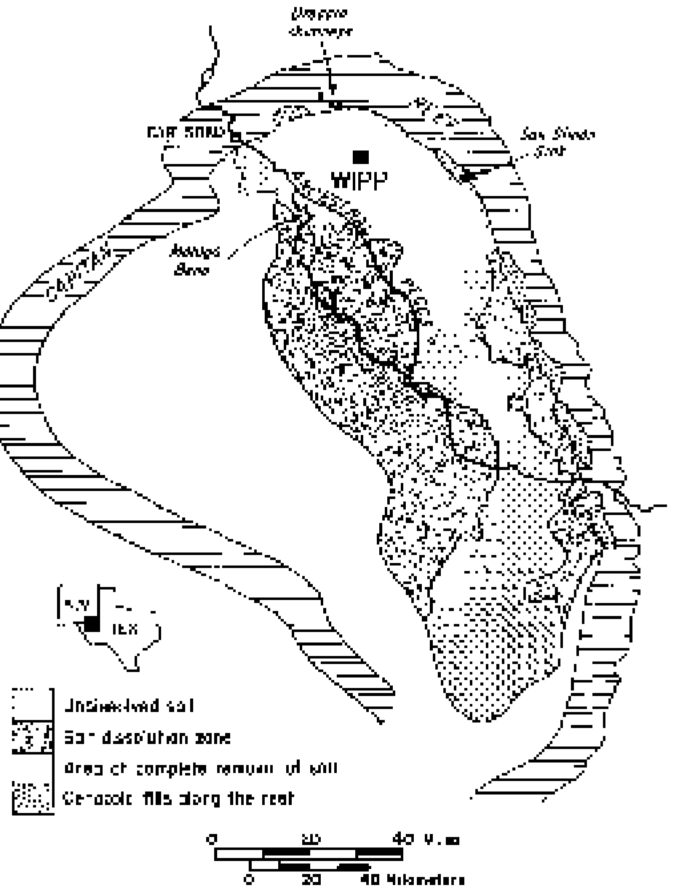


FIGURE 4. Regional extent of removal of salt from the Salado Formation.

the measured hydraulic heads, about 10 to 15 mi (16–24 km) north of the WIPP site. At the WIPP site, the three units are separated but are probably interconnected in Nash Draw, west and southwest of the site. Of the three Rustler units, the Magenta and the Culebra are of prime concern because they extend over the WIPP site, whereas the Rustler–Salado contact zone mainly produces water west of the WIPP site (Mercer, 1983). The majority of testing in the Rustler has concentrated on the Culebra because it is more transmissive than the Magenta and therefore better suited for analyzing bounding breach scenarios.

Results of several single hole and multihole flow tests (Lappin, 1988) at the site indicate that the transmissivities of the Culebra aquifer at and near the WIPP site range from 1000 ft²/day (10^{-3} m²/s) in Nash Draw to 10^{-3} ft²/day (10^{-7} m²/s) east of the WIPP site. Generally, transmissivity increases from east to west across the WIPP site. High transmissivity zones occur in the southeastern part of the site, in the area of boreholes DOE-1 and H-11 and in the north central and northwestern parts in the vicinity of boreholes WIPP-13, DOE-2 and H-6 (Fig. 5).

Chemical composition of ground water from the Culebra aquifer varies widely within short distances at and near the WIPP site (Chapman, 1988). Three miles south of the WIPP site, the Culebra water typically contains 3000 mg/l of total dissolved solids (TDS). At the site itself, TDS varies from 12,500 mg/l at H-2 (Fig. 5) to 130,500 mg/l at H-5. Extreme variation in the chemistry of the Culebra water within short distances is illustrated by the TDS of H-2 (12,500 mg/l), H-3 (154,500 mg/l) and DOE-1 (118,000 mg/l), within a distance of less than 2 mi.

The WIPP is situated in a mineral-rich area. Potash minerals are mined around the WIPP site from the McNutt potash zone in the upper part of the Salado Formation, approximately 1500 ft (450 m) below the surface. Oil and gas are produced around the WIPP site from the Permian Delaware Mountain Group and Pennsylvanian Atokan and Morrowan strata.

STATUS OF WIPP-RELATED GEOLOGICAL ISSUES

History of WIPP site characterization

The geological site characterization for the WIPP began in 1974, following the abandonment of the Lyons, Kansas site in 1972. A 2 mi by 1.5 mi (3.2 km × 2.4 km) rectangular site was selected by the Oak Ridge National Laboratory (ORNL) about 7 mi (11.2 km) northeast of the present site. Cores from two boreholes (AEC 7 and AEC 8, Fig. 5) 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 for WIPP in 1975. A third borehole (ERDA 6), drilled by SNL in the northwest corner of that original 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 2709 ft (826 m). The present site was selected by the SNL and the U.S. Geological Survey (USGS) and a stratigraphic borehole (ERDA-9) was drilled in 1976 through the Salado Formation at the center of the new 2.5 mi by 2.5 mi (4 km × 4 km) WIPP site.

Early site characterization activities focused on obtaining basic data on the stratigraphy, hydrology and potash resources at the WIPP site. As these studies progressed, several geologic features or processes that were potentially deleterious to a radioactive waste repository were identified. The EEG organized a meeting of geoscientists in January 1980, and a field trip in June 1980, to discuss these geologic issues (EEG, 1980; Chaturvedi, 1980). Based on the recommendations from these meetings and independent analyses by the EEG scientists, the EEG proposed preparation of a number of topical reports to address the geological issues that had surfaced at that time. These recommendations were accepted by the DOE and a Stipulated Agreement between the State and the DOE was signed on 1 July 1981, that included the DOE commitment to prepare eleven "topical reports" and six "additional investigations." As a part of additional investigations, the DOE deepened the borehole WIPP-12, located 1 mi north of the center of the WIPP site, from its 1978 completed depth of 2737.5 ft (834.5 m) at the top of the Castile, to a total depth of 3927.5 ft (1197.4 m). Pressurized brine associated with hydrogen sulfide gas was encountered at a depth of 3016 ft (919.5 m). As a result, the DOE, following the EEG recommendation, again relocated the repository about 1.25 mi (2 km) south of the planned location that would have brought the repository within a few hundred feet of the WIPP-12 borehole.

The WIPP topical studies were published in 1983 and the DOE claimed that the geologic site characterization issues were resolved. The EEG reviewed the reports and concluded (Neill et al., 1983) that the site characterization work completed until then warranted confidence in the site, but work still remained to be done to answer the remaining questions. Underground excavation began in 1982 and additional issues came to light from the observations underground.

The more important geologic issues relevant to WIPP are described below and the status of their resolution is discussed.

Dissolution of Salado salt

There is indisputable evidence that the Ochoan evaporite deposits (Castile, Salado, Rustler and Dewey Lake formations) have undergone erosion and blanket dissolution in the Delaware Basin. The edges of the Castile and the Salado halite can be traced west of the Pecos River essentially running parallel to it in a northwest-southeast direction (Anderson, 1981).

Based on a 600,000 year dating of the Pearlette O ash layer exposed at the ridge on the 200 ft (61 m) deep Nash Draw margin, Bachman (1980, 1981) calculated an average rate of 330 ft (100 m) per million years for the vertical dissolution. Assuming that the edge of the Salado salt has moved from the Capitan Reef front to its present location during the past 7 to 8 Ma (since Ogallala time), Bachman and Johnson (1973) concluded that the horizontal rate of movement of the blanket dissolution front is about 6 to 8 miles per million years. These are, of course, very rough average rates of movement; the front itself may have moved faster under less arid climatic conditions. Also, an advancing "tongue" of the front may reach a point faster than the front itself. Using the

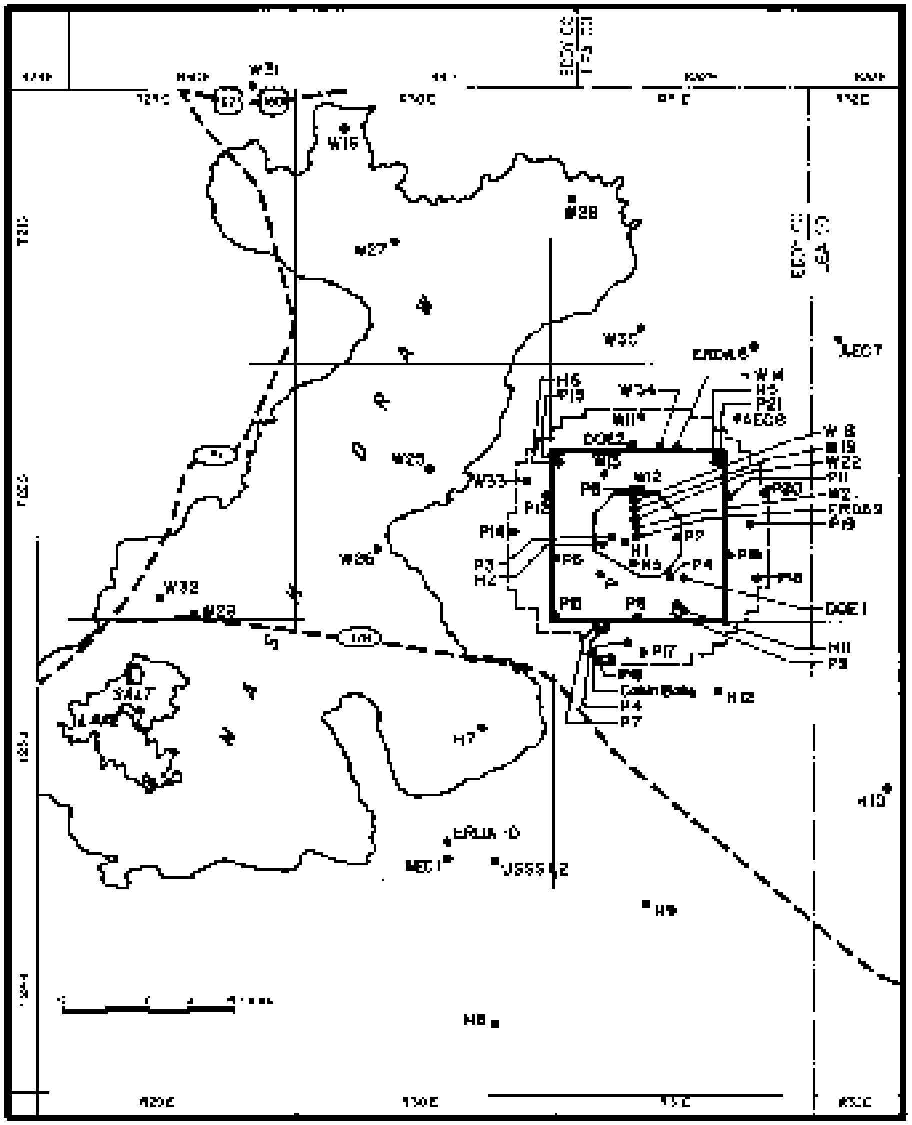


FIGURE 5. The location of boreholes drilled in connection with the WIPP project.

above rates for horizontal and vertical dissolution, it would take approximately 225,000 years for the front to travel approximately 2 mi to reach the western edge of the WIPP site and start dissolving salt from the upper Salado, about 1500 ft (457 m) above the repository horizon. It would then require at least 2 to 3 Ma for the removal of 1500 ft (457 m) of salt by dissolution, at the rate of 330 to 500 ft (100 to 150 m) per million years. In spite of the very approximate nature of the estimated rates of advance of the dissolution front and the possibility of a more rapid advance of a segment of the front, these calculated rates provide sufficient safety from an advancing front of blanket shallow dissolution of salt toward the WIPP site.

In addition to the blanket dissolution of salt described above, Anderson et al. (1972) raised the possibility of a different kind of dissolution process acting at depth from the margins of the basin by noting that large quantities of bedded salt were missing from the middle of the evaporite sequence near the center of the basin. Using the correlation of acoustic logs across several lines in the Delaware Basin, Anderson (1978) concluded that (1) the preferred horizons from which salt has been removed by dissolution occur between the Halite III salt of the Castile Formation and the 136 marker bed of the Salado Formation and (2) the large depressions in the basin, first identified by Maley and Huffington (1953), were the result of selective dissolution of lower Salado salt beds. Anderson (1981) further developed the idea of deep-seated dissolution and concluded that such dissolution has occurred around the margin of the basin where the Capitan aquifer is in contact with the Permian evaporites, and within the basin where selective dissolution in the lower Salado has undercut the overlying salt beds. He calculated that more than 70% of the original salt has already been removed from the lower Salado horizon in the basin.

As requested by the EEG, Lambert (1983) prepared a topical report on the dissolution issue for the WIPP project. Another WIPP project report (Wood et al., 1982) examined the viability of the Delaware Mountain Group aquifer removing the dissolved salt, as hypothesized by Anderson (1981). The EEG (Chaturvedi, 1980; Neill et al., 1983; Chaturvedi and Rehfeldt, 1984) examined the deep-dissolution hypothesis and concluded that although the timing and the mechanism were not fully explained by the hypothesis, the evidence from geophysical well logs did indicate that a large amount of salt from the lower Salado units was missing. However, there were eight WIPP project boreholes (AEC-7 and AEC-8 to the northeast, ERDA-10 to the southwest, WIPP-11 to the north and WIPP-9, 12, 13 and DOE-1 within the WIPP site, see Fig. 5), which had obtained cores of the Salado Formation but did not show any evidence of extensive dissolution. From this, the EEG concluded (Chaturvedi and Rehfeldt, 1984) that the Salado Formation does not appear to have been affected in and around the WIPP site by past regional dissolution at depth, although an area located 2 mi (3.2 km) north of the center of the WIPP site was suspected as a potential area of point-source dissolution. At the urging of the EEG, the DOE drilled a 4325 ft (1319 m) deep corehole (DOE-2, Fig. 5) to investigate the origin of this feature, which was identified as a structural depression on the basis of observed depression in the anhydrite/clay marker-beds in the potash industry boreholes.

The core from the DOE-2 borehole confirmed the existence of the structural depression but showed no indication of this being due to dissolution at depth. The absence of any dissolution residue and a thickened halite section can best be interpreted as due to gravity-driven salt flow in the area (Borns, 1987). The WIPP repository is no longer considered to be threatened by the effects of the Salado salt dissolution at depth.

Breccia chimneys

A breccia chimney is a solution-subsidence structure formed by dissolution of an evaporite layer at depth that results in collapse of the overlying layers, thus forming a brecciated chimney up to several thousand feet in diameter with its base in the collapsed cavity. These features are found in many evaporite basins of the world. With respect to the WIPP, the concern was that a breccia chimney may form under the WIPP repository sometime in the future, thereby providing a potential pathway for breach of the repository.

Vine (1960) identified as possible breccia chimneys several domal structures in the Delaware Basin that have been explored during the investigations for WIPP. After extensive investigation, the existence of only two chimneys (Hills A and C) was confirmed. Geophysical and geological studies show that two others (Hills B and Wills-Weaver) are also likely breccia chimneys, although they were not cored. All of these features appear to be situated over the Capitan Reef limestone, which is a prolific aquifer in the area. Davies (1983) pointed out that the Hill "C" breccia pipe is located at the southern edge of the buried Capitan Reef and since the borehole WIPP-16, drilled to explore this chimney, was drilled only to the level of the McNutt potash zone of the Salado Formation, it is not clear whether the Hill "C" breccia chimney roots in the Capitan aquifer.

Besides boreholes WIPP-31 and WIPP-16, which were drilled at Hills A and C, respectively, to investigate the breccia chimneys, three other boreholes were drilled at suspected breccia chimney locations in the basin. Borehole WIPP-32 was drilled in a small topographic high in Nash Draw, which had been described by Vine (1963) as a domal karst feature. These features (domal karst) have been extensively studied by Bachman (1980, 1984). Boreholes WIPP-13 and WIPP-33 were also drilled to explore for possible breccia chimneys. There is a marked electrical resistivity anomaly at WIPP-13 and a prominent topographic depression exists at the location where WIPP-33 was drilled. Collapsed breccia was not found at either of the wells.

Anderson and Kirkland (1980) described the occurrence of collapse breccia in a borehole in Culberson County, Texas, about 55 mi south of the WIPP site. Anderson (in Chaturvedi, 1980) described occurrences of "castiles," which are mounds of brecciated rock that crop out a few miles south of the New Mexico–Texas border, south of the WIPP site. Both occurrences are in the exhumed western part of the Delaware Basin, which has already undergone extensive dissolution.

Snyder and Gard (1982) studied the known occurrences of breccia chimneys in the Delaware Basin. They studied in detail the Hill "C" breccia chimney, which is also encountered at the McNutt potash zone of the Salado Formation in the Mississippi Chemical Company potash mine, 1200 feet (366 m) below the surface. From study of this exposure, the core of WIPP-16 drilled in this chimney and the core of WIPP-31 drilled in the Hill "A" breccia chimney, Snyder and Gard (1982) concluded that the breccia chimneys are formed by collapse of the overlying rocks in solution cavities in the Capitan Reef aquifer. Bachman (1980) hypothesized that the location of all the known breccia pipes in a small area over the reef is due to the presence of an old submarine canyon in the reef in this area. On the basis of the presence of Mescalero caliche over the breccia pipes, Bachman (1980) also concluded that the collapse occurred prior to the deposition of this caliche layer, i.e., more than 0.5 Ma.

Davies (1984) also studied chimneys A and C and concluded that they were produced by salt dissolution at the base and within the lowermost portion of the Salado Formation, through incremental subsidence rather than catastrophic collapse of the overlying strata. The EEG concluded (Neill et al., 1983) that the probability of a breccia chimney forming under the WIPP site was fairly remote and that this phenomenon did not appear to pose a threat to the WIPP repository.

Brine reservoirs

Within a few miles of the WIPP site there are at least sixteen reported encounters of pressurized brine in the upper anhydrite layer of the Castile Formation (Fig. 6). Two of these encounters (ERDA-6 and WIPP-12, Fig. 5) were in the WIPP project boreholes and the rest have been reported by oil and gas drilling companies. When borehole WIPP-12, located 1 mi (1.6 km) north of the center of the WIPP site, hit brine at a depth of 3016 ft (919.5 m), brine started flowing out of the well at a rate of 350 gallons per minute (22 liters/sec) and more than 1.14 million gallons (4.3 million liters) of brine flowed out before the well was controlled. Based on an extensive series of flow tests, the brine reservoirs penetrated by the WIPP-12 and ERDA-6 boreholes were estimated to contain 17 million barrels (2.7 billion liters) and 630,000 barrels (100 million liters) of brine, respectively (Popielak et al., 1983). The different pressure potentials and geochemical data from the two encounters suggested a lack of communication between the ERDA-6 and WIPP-12 brine reservoirs. There was no consensus on the origin and the age of the brine reservoirs.

The planned configuration of the WIPP repository and the WIPP experimental areas would have brought the waste within 460 ft (140 m) south of the WIPP-12 borehole. The EEG recommended moving the repository in 1982 and the DOE rotated the repository configuration to relocate the nonwaste experimental area to the north and the repository 1.2 mi (2 km) south of WIPP-12. In 1983, EEG formally proposed geophysical investigations to delineate the extent of pressurized brine in the Castile Formation underlying the WIPP site and particularly under the new location of the repository. The work was performed in 1987, and the results gave a clear indication of the presence of brine under parts of the WIPP repository (Earth Tech. Corp., 1988).

The presence of brine reservoirs in the Castile Formation is a major geological issue affecting the anticipated performance of the repository. Since there are good geophysical indications of the presence of brine in the Castile Formation, 800 ft (244 m) or so below the repository, the inadvertent drilling to a brine reservoir through the repository is a scenario that the WIPP project has to evaluate. Such a drilling sometime during the next 10,000 years would allow pressurized brine to flow into the repository. Several pathways for injection of such contaminated brine into the Rustler Formation or directly to the surface have been postulated.

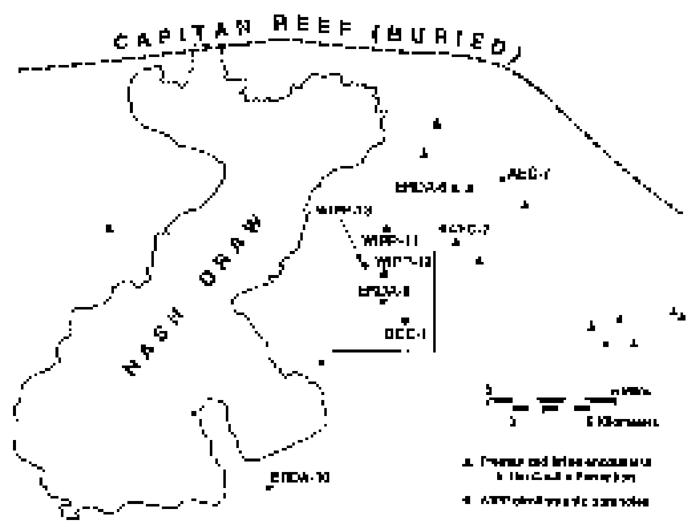


FIGURE 6. Pressurized brine encounters in the Castile Formation in the vicinity of the WIPP site.

Salado brine

A reason for selecting bedded salt deposits for isolating radioactive waste was the assumption that salt would be essentially dry. One of the surprises encountered by in situ underground studies at the WIPP is that the Salado salt yields a fair amount of water. A large percentage of boreholes drilled down from the WIPP excavations fill up with brine and the walls are covered with efflorescences and encrustations resulting from brine inflow from salt into the excavation and drying up by ventilated air. Several boreholes completed in the Salado Formation indicate fluid pressure buildup (Mercer, 1987). In situ Salado salt has low (10^{-21} m²), but measurable, permeability.

Bredehoeft (1988) proposed that the Salado salt is saturated with brine and exhibits Darcian flow. Nowak et al. (1988) calculated that for salt permeabilities of 10^{-21} to 10^{-20} m² (1 to 10 nanodarcies), between 4 m³ to 43 m³ of brine would accumulate in a typical WIPP repository room with dimensions of 300 ft × 33 ft × 13 ft (91.5 m × 10 m × 4 m). Since the WIPP CH TRU containers are ordinary 55-gallon mild carbon steel drums that are not expected to last much beyond their 20-year design life, the brine would mix with the TRU waste and may form a slurry. Sandia National Laboratories (1987) calculated that if someone drills into such brine slurry and inadvertently brings a part of it to the surface, EPA Standards may be violated.

Corrosion of the metal containers and metal in the waste would produce hydrogen. Microbiological degradation of the organic material in the waste would produce carbon dioxide and methane. These processes require water to produce gas and the Salado brine inflow will satisfy that need. The rate of brine inflow in the repository is therefore a very important parameter for assessing breach scenarios. DOE has been monitoring and sampling the Salado brine from 13 boreholes in the WIPP underground since 1984 (Deal et al., 1991). After five years of observation, five 50 ft (15 m) deep holes have remained steady producers of brine, one showing increased brine production and five showing decreasing rates. One seep in the floor has produced between 0.15 to 0.2 gallons (0.5 to 0.75 liters) of brine per day for five years. Several holes in the roof and in the walls also have been producing brine.

Hydraulic testing of the Salado Formation at the WIPP repository horizon (Beauheim et al., 1993) shows the brine flow in the Salado salt to be Darcian in nature because the Darcy flow models are able to replicate the flow and the pressure behavior observed during the entire testing sequences involving different types of tests. The estimation of brine inflow by Nowak et al. (1988) appears to be on sound theoretical basis. Estimation based on actual inflow observation for a long time, under progress now, would provide confirmatory evidence of this calculation.

Rustler Formation hydrology

The Culebra dolomite member of the Rustler Formation, being the most prolific of the three water-bearing zones overlying the WIPP repository, is the most likely pathway for transport of radionuclides after a breach of the repository. Based on three multiwell flow tests, several single-well flow tests and nonsorbing tracer tests at four hydropads, LaVenue et al. (1990) performed ground water flow modeling of the Culebra at the WIPP site. The flow model suggests that if radionuclides are injected into the Culebra directly above the repository panels near the center of the WIPP site, the fastest flow path out of the WIPP area would be to the south-southeast past the boreholes H-3 and H-11 (Fig. 5).

The calculated travel time for contaminant transport along this pathway, however, is very sensitive to assumptions of fracturing in the Culebra dolomite and distribution of contributing porosity between the rock matrix and the fractures. If double-porosity flow is assumed, with diffusion of contaminants in the rock matrix, the shortest travel time from the center of the WIPP site to the southern boundary is 14,000 years. If, on the other hand, transport is assumed through fractures only (single porosity), then the travel time would be less than 100 years. Additional multiwell flow tests are required to better define the transmissivity field at the WIPP site. Additional tracer tests designed to better define the fracture vs. matrix porosity flow are also needed. The breach scenario calculations have identified radionuclide retardation during contaminant transport through the Culebra as one of the sensitive parameters that control the magnitude and timing of the postulated releases of radioactivity to the environment. Field and laboratory experiments are required to provide reliable and justifiable numbers for physical and chemical retardation. Laboratory experiments are being set up and initial results are expected in 1993 or 1994.

The WIPP site is situated in a gypsum karst area. The subsidence feature called Nash Draw has been formed by the karstic process of solution and fill (Lee, 1925; Bachman, 1980, 1984). The depression in which borehole WIPP-33 (Fig. 5) was drilled is a karst sink. No positively identified karst feature has been encountered east of WIPP-33 in the WIPP area, nor have hydrologic tests in the area detected any channelized flow. Breach scenario calculations have not considered potential releases through channelized flow or through narrow transmissive layers due to vertical heterogeneity. Such conceptual models would result in greater releases, as shown by Chaturvedi and Channell (1985).

Beauheim and Davies (1992) have proposed a seven-well flow and tracer test to be fielded between H-6 and DOE-1. This test is designed to address the questions of vertical heterogeneity and matrix diffusion and would provide data to better characterize the flow mechanism. It is also intended to use the instruments for a field sorbing tracer test for providing data on chemical retardation processes and properties within the Culebra. This test is planned to begin in 1995.

Disturbed rock behavior

Before underground excavation at WIPP began in 1982, DOE scientists performed calculations to predict the closure history of the excavations. These calculations used the geomechanical properties of the rock strata at the selected WIPP repository horizon obtained from testing of the rock cores from boreholes. The calculations predicted that a WIPP room would "close slowly in a stable manner as the salt creeps" and "relative closure values of 0.21 m (8.25 in.) in the vertical direction and 0.28 m (11 in.) total in the horizontal direction are seen for the isothermal room after 10 years" (Miller et al., 1982). The WIPP excavations have behaved very differently than predicted. Vertical closure in the WIPP test rooms has varied between 3 in. (75 mm) and 4 in. (100 mm) *per year* and horizontal closure has ranged between 2 in. (50 mm) and 3 in. (75 mm) *per year*. A "disturbed rock zone" consisting of fractured rock surrounds all the excavations. In less than eight years after excavation, the roof of the first of the four test rooms fell in February 1991, due to fractures propagating above the roof and creating an up to 7 ft (2 m) wide unstable trapezoidal beam between the roof and a thin layer of anhydrite above the roof.

The difference between the predicted and measured closure rates has been explained on the basis of use of the wrong geomechanical models and not taking into account the details of the stratigraphy (Munson et al., 1989). While the faster closure rate will help entomb the waste sooner, it creates problems during operations. The WIPP repository rooms should be excavated just before they are needed for waste emplacement and backfilled soon thereafter. It will also create problems in maintaining retrievability of the waste. Due to its interaction with brine inflow and gas pressure from gases produced by the waste, the room closure rate also affects long-term performance of the repository.

Natural resources

The WIPP site is located in a region that contains substantial amounts of potash, natural gas and petroleum resources. Therefore, breach scenarios involving inadvertent drilling by future generations must be considered. The EPA Standards 40 CFR 191 (EPA, 1985, App. B) prescribed a limit of assuming 30 boreholes/km²/10,000 years, which was based on the drilling frequency in the WIPP site vicinity in 1970s. Judging by the number of producing wells, drilling activity around the WIPP site in 1992 and the number of applications to the U.S. Bureau of Land Management for new drilling permits, the oil and gas resources in the WIPP area are much more prolific than previously considered. This fact must be taken into account in the assessment of the WIPP's compliance with the EPA Standards.

CONCLUSIONS

Since the WIPP repository is designed to rely on geologic isolation for 10,000 years, consideration of the various geologic features and processes are very important to assess the capability of the site to keep the waste isolated from the environment. The impact of the potentially deleterious geologic factors on the repository will be judged on the results of consequence analyses of potential breach scenarios.

ACKNOWLEDGMENTS

Without John Hawley's persuasive talent and enormous patience, this paper would not have been written. Carol Hill and Thomas Corbet reviewed the paper and made many useful suggestions. Betsy Kraus prepared the list of references in the correct format at a short notice and also provided review comments. Jill Shortencarier patiently and competently typed the manuscript.

REFERENCES

Anderson, R. Y., 1978, Deep dissolution of salt, northern Delaware Basin, New Mexico: Report to Sandia Laboratories, 106 p.

Anderson, R. Y., 1981, Deep-seated salt dissolution in the Delaware Basin, Texas and New Mexico: New Mexico Geological Society, Special Publication 10.

Anderson, R. Y., Dean, W. E. Jr., Kirkland, D. W. and Snider, H. I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geological Society of America Bulletin, v. 83, p. 59–86.

Anderson, R. Y. and Kirkland, D. W., 1980, Dissolution of salt deposits by brine density flow: Geology, v. 8, p. 66–69.

Bachman, G. O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern N.M.: U.S. Geological Survey, Open-file Report 80-1099, 116 p.

Bachman, G. O., 1981, Geology of Nash Draw, Eddy County, New Mexico: U.S. Geological Survey, Open-file Report 81-31.

Bachman, G. O., 1984, Regional geology of the Ochoan evaporites, northern part of the Delaware Basin: New Mexico Bureau of Mines and Mineral Resources, Circular 184, 22 p.

Bachman, G. O. and Johnson, R. B., 1973, Stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas and New Mexico: U.S. Geological Survey, Open-file Report 4339-4.

Beauheim, R. L. and Davies, P. B., 1992, Experimental plan for tracer testing in the Culebra Dolomite at the WIPP site, Revision A, October 15: Albuquerque, Sandia National Laboratories.

Beauheim, R. L., Dale, T., Fort, M., Roberts, R. and Stensrud, W. (in press), Hydraulic testing of Salado Formation evaporites at the Waste Isolation Pilot Plant site: second interpretive report, SAND92-0533: Albuquerque, Sandia National Laboratories.

Borns, D. J., 1987, Geologic structures observed in drill hole DOE-2 and their possible origins, SAND86-1495: Albuquerque, Sandia National Laboratories.

Bredehoeft, J. D., 1988, Will salt repositories be dry?: EOS, Transactions of the American Geophysical Union, v. 69, p. 121–131.

Chapman, J. B., 1988, Chemical and radiochemical characteristics of ground water in the Culebra Dolomite, southeastern New Mexico, EEG-39: Albuquerque, Environmental Evaluation Group, 63 p.

Chaturvedi, L., 1980, WIPP site and vicinity geological field trip, a report of a field trip to the proposed Waste Isolation Pilot Plant project in southeastern New Mexico, June 16 to 18, 1980, EEG-7: Santa Fe, Environmental Evaluation Group, 148 p.

Chaturvedi, L. and Channell, J. K., 1985, Rustler Formation as a transport medium for contaminated ground water, EEG-32: Santa Fe, Environmental Evaluation Group, 85 p.

Chaturvedi, L. and Rehfeldt, K., 1984, Ground water occurrence and the dissolution of salt at the WIPP radioactive waste repository site: EOS, Transactions of the American Geophysical Union, v. 65, p. 457–459.

Davies, P. B., 1983, A review of the USGS Open File Report 82-968, "Evaluation of breccia pipes in southeastern New Mexico and their relation to the WIPP site" by Snyder, R. P. and Gard, L. M. Jr., prepared for EEG.

Davies, P. B., 1984, Deep-seated dissolution and subsidence in bedded salt deposits [Ph.D. dissertation]: Stanford, CA, Stanford University, 379 p.

Deal, D. E., Abitz, R. J., Belski, D. S., Clark, J. B., Crawley, M. E. and Martin, M. L., 1991, Brine sampling and evaluation program, 1989 report, DOE-WIPP 91-009: Carlsbad, New Mexico, U.S. Department of Energy, WIPP Project Office.

Earth Technology Corporation, 1987, Time domain electromagnetic (TDEM) surveys at the WIPP site, final report, SAND87-7144: Albuquerque, Sandia National Laboratories.

Environmental Evaluation Group, 1980, Geotechnical considerations for radiological hazard assessment of WIPP, a report of a meeting held on January 17–18, 1980, EEG-6: Santa Fe, Environmental Evaluation Group, 69 p.

Hiss, W. L., 1976, Stratigraphy and ground-water hydrology of the Capitan Aquifer, southeastern New Mexico and west Texas [Ph.D. dissertation]: Boulder, University of Colorado.

Lambert, S. J., 1983, Dissolution of evaporites in and around the Delaware Basin, southeastern New Mexico and west Texas, SAND82-0461: Albuquerque, Sandia National Laboratories.

Lappin, A. R., 1988, Summary of site-characterization studies conducted from 1983 through 1987 at the Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico, SAND88-0157: Albuquerque, Sandia National Laboratories.

LaVenue, A. M., Cauffman, T. L., Pickens, J. F. and McCord, J. P., 1990, Ground water flow modeling of the Culebra Dolomite, SAND89-7068: Albuquerque, Sandia National Laboratories, 2 v.

Lee, W. T., 1925, Erosion by solution and fill: U.S. Geological Survey, Bulletin 760-D, p. 107–121.

Lowenstein, T. K., 1987, Post burial alteration of the Permian Rustler Formation evaporites, WIPP site, New Mexico, EEG-36: Santa Fe, Environmental Evaluation Group, 54 p.

Maley, V. C. and Huffington, R. M., 1953, Cenozoic fill and evaporite solution in Delaware Basin, Texas and New Mexico: Geological Society of America Bulletin, v. 64, p. 539–546.

Mercer, J. W., 1983, Geohydrology of the proposed Waste Isolation Pilot Plant site, Los Medanos area, southeastern New Mexico: U.S. Geological Survey, Water-Resources Investigations Report 83-4016.

Mercer, J. W., 1987, Compilation of hydrologic data from drilling the Salado and Castile Formations near the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico, SAND86-0954: Albuquerque, Sandia National Laboratories, 39 p.

Munson, D. E., Fossum, A. F. and Senseny, P. E., 1989, Advances in resolution of discrepancies between predicted and measured in situ WIPP room closures, SAND88-2948: Albuquerque, Sandia National Laboratories, 77 p.

Neill, R. H., Channell, J. K., Chaturvedi, L., Little, M. S., Rehfeldt, K. and Spiegler, P., 1983, Evaluation of the suitability of the WIPP site, EEG-23: Santa Fe, Environmental Evaluation Group, 157 p.

Nowak, E. J., McTigue, D. F. and Beraun, R., 1988, Brine inflow to WIPP disposal rooms: data, modeling and assessment, SAND88-0112: Albuquerque, Sandia National Laboratories, 76 p.

Popielak, R. S., Beauheim, R. L., Black, S. R., Coons, W. E., Ellingson, C. T. and Olsen, R. L., 1983, Brine reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) project, southeastern New Mexico, TME-3153: Albuquerque, U.S. Department of Energy, Waste Isolation Pilot Plant.

Powers, D. W., Lambert, S. J., Shaffer, S. E., Hill, L. R. and Weart, W. D., eds., 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) site, Southeastern New Mexico: Albuquerque, Sandia National Laboratories, SAND78-1596, 2 vols.

Powers, D. W. and Holt, R. M., 1990, Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site: Geological Society of America, 1990 Annual Meeting Field Trip, Guidebook 14, p. 79–106.

Sandia National Laboratories, Performance Assessment Group, 1987, Early PA Scoping calculations, memo to distribution, April 7, unpublished.

Snyder, R. P. and Gard, L. M. Jr., 1982, Evaluation of breccia pipes in southeastern New Mexico and their relation to the WIPP site: U.S. Geological Survey, Open-file Report 82-968, 73 p.

U.S. Code of Federal Regulations, 1985, Environmental Protection Agency, Environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes, Part 40, Title 191.

U.S. Code of Federal Regulations, 1991, Environmental Protection Agency, Land disposal restrictions, Part 40, Title 268.

Vine, J. D., 1960, Recent domal structures in southeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 44, p. 190.

Weart, W. D., 1983, Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) site suitability, SAND83-0450: Albuquerque, Sandia National Laboratories.

Wood, B. J., Snow, R. E., Cosler, D. J. and Haji-Djafari, S., 1982, Delaware Mountain Group (DMG) hydrology—salt removal potential, TME-3166: Albuquerque, U.S. Department of Energy, Waste Isolation Pilot Plant, 136 p.

8.6 Letter Reports of EEG Consultants on the K_d Issue

Donald Langmuir, PhD
Hydrochem Systems Corporation
129 South Eldridge Way
Golden, CO 80401

August 5, 1997

Dr. Robert H. Neill
Director, Environmental Evaluation Group
7007 Boulevard, N.E., Suite F-2
Albuquerque, NM 87109

Dear Bob:

Following are some thoughts based on my attendance at the DOE/EEG Meeting on Chemical Retardation in Albuquerque on July 30, 1997, and on related reading. I have ordered the discussion topics as they were set forth by Dr. Lokesh Chaturvedi of EEG in his introductory presentation.

Transferability of Lab K_d Data to Field

Transferability has always been an issue of concern. My understanding is that a consensus now exists that groundwater flow in the Culebra is slow enough to guarantee that important diffusion of the groundwater into rock matrix will occur. If this is the case then the radionuclides in groundwater will have ample opportunity to access mineral surfaces in pores in the dolomite, making laboratory measured batch K_d values applicable to the field.

The Limited K_d Data Base

The limited K_d data base remains a serious problem. We can all agree that K_d values for the important actinides Pu, Am and U, regardless of oxidation state, probably equal or exceed 1 ml/g in Culebra groundwaters, which is necessary for compliance. However, the hydrologic model for the Culebra and associated groundwater flow mechanisms and travel times in the formation have non-zero uncertainties. It is unclear how much these hydrologic uncertainties contribute to the uncertainty of assigning a minimum compliance K_d value of 1 ml/g. Given this additional hydrologic uncertainty, if I were a regulator, I would be much more confident that the site was in compliance if the DOE's recommended K_d's for the important actinides were at least 10 to 100 times greater than 1 ml/g. As discussed below, the approach used by the DOE for estimating unmeasured K_d values involves questionable assumptions.

K_d Estimation Methods used by the DOE

The DOE proposes that K_d values for actinide cations of the same charge should be roughly the same. This approach has been used by many others. (See discussion below). Its weakness lies in the fact that such approximations assume that differences in the speciation behavior of the cations does not affect their adsorption and can be neglected.

The second assumption used by the DOE to estimate K_d values, is that predictable trends exist among the K_d's of actinide cations of different charge. The DOE assumed that such trends identified by Canepa (1992)[1] in dilute, J-13 groundwaters at Yucca Mountain would apply to WIPP brines. Canepa (1992) proposed that K_d values for actinides in J-13 groundwater should decrease in the same order as their solubilities increased in the same groundwater. The reported solubility data for U(VI), Np(V), Pu(IV)[2] and Am(III) plotted linearly, seeming to support her contention. This led to the proposal that K_d values should decrease in the order Am(III)>Pu(IV)?>Np(V)>U(VI). The DOE has suggested that the same order of K_d values should apply in groundwaters at the WIPP site. However, recent solubility measurements performed at LANL indicate that Np(V) solubility is about 10 times lower than assumed by Canepa (1992). The computed solubility of Np in J-13 groundwater is in fact as low as 10^{-7} mol/L (Langmuir, 1997, p. 534)[3], about 10^{1} less than suggested by Canepa (1992). Similarly, the solubility of U(VI) in J-13 groundwater may also be about 10^{-7} mol/L, 10^{2} to 10^{3} times lower than proposed by Canepa (cf. Langmuir, 1997, p. 533). Assuming as did Canepa (1992), that the actinide solubilities in J-13 groundwater should be inversely proportional to their K_d values, these changes suggest that the order of decreasing K_d's in J-13 and in WIPP groundwaters should be Am(III)>U(VI)>Pu(IV)>Np(V).

In fact, in general K_d values are probably not inversely proportional to the solubilities of the actinides. Thus, in a summary of adsorption trends among the actinides, Langmuir (ibid, p. 536) reports that K_d's decrease in the order Th(IV)>Am(III)>Np(V) for the adsorption of these actinides by Al_2O_3 as evidenced by respective pH values of 2.4, 5.8, 7.3 at 50% of each species adsorbed. Similarly, as pH is increased, goethite has adsorbed 50% of Pu(IV), U(VI) and Np(V) at pH values of 3.2, 4.2 and 7.0, respectively. This is therefore also the order of their decreasing K_d's (Langmuir, ibid, p. 537). Also, based on a literature survey, Silva and Nitsche (1996)[4] propose a general order of decreasing K_d's for the adsorption of actinides (An elements) by the same sorbents, of An(IV)>An(III)>An(VI)>An(V), in general agreement with the abbreviated adsorption series listed previously. Based on the plot of Canepa (1992), the DOE argues in the CCA, that estimated K_d values for Am(III) and Pu(III) should be greater than the measured K_d for Pu(V). Although their conclusion is based on the questionable data and assumptions in Canepa (1992), the same trend of K_d values for these species is fortuitously observed within the adsorption trends for the actinides reported by Langmuir, (1997) and Silva and Nitsche, (1996).

Availability and Reliability of Measured K_d Values

At the July 30, 1997 meeting in Albuquerque, the DOE presented the results of adsorption measurements performed in both column and batch tests. Results of the intact core column tests are probably of questionable value for determining Am(III) and Pu (V) (Pu(IV)?) adsorption K_d's , in that the Am and Pu input concentrations to the cores were high and so close

---

[1]Los Alamos National Laboratory

[2]The oxidation state of Pu may have been a mixture of IV, V, and VI.

[3]Aqueous Environmental Geochemistry. Prentice Hall, Upper Saddle River, NJ. 600 pp.

[4]Actinide Environmental Chemistry. Radiochim. Acta, in press.

to saturation with solids, that precipitation rather than adsorption may have occurred. The Th(IV) column adsorption experiments and their results were not discussed at the meeting.

Useful batch adsorption results have been reported for Pu(V), U(VI), Th(IV) and Np(V). Performance assessment indicates that the important actinides at WIPP are Pu and Am, with U of tertiary importance. Based on oxidation state predictions, Pu(III) and Pu(IV) are the dominant Pu oxidation states in WIPP brines. Unfortunately, Am(III) batch adsorption experiments have given inconclusive results, and batch adsorption of Pu(III) and Pu(IV) has not been measured. Thus, the K_d values for the most important actinides in WIPP brines have had to be estimated.

K_d Values Chosen for the CCA

In the CCA, it was conservatively assumed that the lowest K_d values measured in the Culebra Dolomite or deeper Castile or Salado brines would be assumed for performance assessment (PA). Ranges of K_d values for the actinide cations proposed in the CCA are given in Table 1.

Table 1. K_d values used by DOE in the WIPP 1996 Compliance Certification Application (CCA) (assumes uniform distribution). Bold values are based chiefly on batch adsorption measurements discussed by L.H. Brush in his June 10, 1996 memo to M.S. Tierney of Sandia Natl. Laboratories. The probable order of decreasing K_d's in column 7 is based on earlier discussion in the text.

Oxidation State	Am	Pu	U	Th	Np	Probable Order of Decreasing K_d's
III	20-500 (no data)	20-500 (no data)				2
IV		900-20,000 (no data)	900-20,000 (no data)	**900-20,000**	900-20,000 (no data)	1
V		**20-500**			**1-200**	4
VI			**0.03-30**			3

The DOE reported a measured batch K_d of 20-500 ml/g for Pu(V), a species not expected in WIPP brines. Based on adsorption trends, the K_d for Am(III) and Pu(III) should be greater than its value for Pu(V). Given this assumption, the DOE conservatively assumes the K_d for Am(III) and Pu(III) equals the range measured for Pu(V). One could as well argue that the lower measured K_d range of 1-200 ml/g for Np(V) adsorption could instead have been assumed conservatively for Am(III) and Pu(III).

In summary, the most important actinides in WIPP brines are Pu(III), Pu(IV) and Am(III). The DOE has used the Canepa (1992) report and limited batch adsorption data to estimate K_d values for these actinides in WIPP brines. Although the estimated K_d values used in the CCA are probably conservative, it is most unfortunate that Am(III), Pu(III) and Pu(IV) adsorption has not been measured. I understand that batch adsorption experiments designed to obtain K_d values for these actinides would not be particularly difficult to perform, and might be completed in a few months. It is also possible that accelerated intact column tests could be run in a few months using an ultracentrifuge. Admittedly, resultant K_d's can be predicted to exceed 1-3 ml/g. However, having measured instead of estimated values for the key actinide species would greatly improve confidence that K_d values for the most important actinides are in compliance with regulations.

Solubility Controls on Am, Pu, U and Np Concentrations in WIPP Brines

According to an unpublished July 6, 1996 Sandia report by Stockman and Stockman, titled "Constraints on Actinide Oxidation State in the Culebra: Reaction Path Mixing Calculations", the Culebra Dolomite contains an average of 0.17% FeO. These authors also note that 20 polished sections of the Culebra from 9 WIPP-area boreholes contained pyrite (FeS_2) in every section. The redox state of the rock will ultimately control redox conditions in the WIPP brines. In the absence of a source of free oxygen, reducing conditions are likely to dominate groundwaters away from the waste. Ferric iron staining is common in the Culebra. Eh values in the brines are thus likely to be poised by reactions between either ferroan dolomite and the Fe(III) oxyhydroxides, or pyrite and the Fe(III) oxyhydroxides.

In the vicinity of the waste, iron and nickel metal and organic matter will also tend to deplete any oxygen introduced with the waste. Reduced Fe, S and C in the waste and the rock are likely to cause reduction not only of Pu(V) to Pu(IV) and Pu(III), but may also lead to reduction of U(VI) to U(IV) and Np(V) to Np(IV). If these reductions take place, then maximum concentrations of Pu, U and Np may be limited by the solubilities of their quadrivalent oxides or hydroxides to values of 10^{-8} mol/L or less. If maximum concentrations of Pu and U are so limited, then the adsorption behavior of higher oxidation states may be irrelevant to performance assessment.

In carbonate-rich groundwaters, the concentration of Am(III) is limited by the solubility of Am(III) hydroxy-carbonate to values below 10^{-8} mol/L between about pH 7.5 and 9 (Langmuir, ibid). In WIPP brines at high pH's in the presence of MgO to scavenge the carbonate, $Am(OH)_3$ solubility may limit Am(III) concentrations at similarly low concentrations.

Limited solubility data for these actinides in WIPP brines is available. However, those of An(IV) species in particular are likely to be well below 10^{-8} mol/L in the presence of MgO and in the absence of carbonate. It would be useful for the DOE to evaluate and report on the available solubility data for these actinides measured in WIPP brines and in similar brines. The brine solubilities of analog rare earth cations and analog actinides such as Th(IV) would also shed light on the probable behavior of Am(III), Pu(III) and Pu(IV) in WIPP brines.

Non-Culebra Dolomite

The Kd's for U(VI) adsorption by Norwegian dolomite are within the range of values for U(VI) adsorption by Culebra Dolomite. This is reasonable. That this pure dolomite adsorbed more U(VI) than some Culebra Dolomites that contain other sorbing minerals, does not strike me as an issue of concern.

Effect of Organic Ligands on Actinide Complexing and Adsorption

It seems probable as argued by Vann Bynum, that organic complexing of actinides does not significantly increase their solubilities or adsorption behavior in the vicinity of the waste. This reflects the competition of more abundant cations such as Ni^{2+} , Ca^{2+} and Mg^{2+} for organic ligands such as EDTA. Also important is the fact that actinides such as Th(IV), Pu(IV) and Np(IV) form strong OH complexes at neutral to alkaline pH's so that their free ion concentrations are many orders of magnitude lower than the free ion concentrations of Ni^{2+}, for example. Van Bynum made his calculations ignoring hydrolysis of the actinide cations, and still found less than 1% of Th(IV) complexed with EDTA, the strongest organic complexer. If he had corrected for Th-OH complexing, orders of magnitude less Th would have been complexed by EDTA.

It would be most convincing if the actinide complexation reaction calculations were rerun, but including OH and other inorganic actinide complexing, and varying (increasing) the amount of EDTA in the waste within possible ranges, to more rigorously disprove the importance of actinide-organic complexing near the WIPP waste.

Kd's Based on the Intact Column Test Results

As noted earlier, the Pu(V) and Am(III) column test results are of dubious value for determining K_d values for these actinides. Because of the high concentrations of Pu(V) and Am(III) in intake solutions, they could have been precipitated as solids rather than been adsorbed in the columns. If so, their concentrations in the rock cannot be used to define K_d values. In order to prove or disprove this concern, if possible, 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 3-D solid phase form. It is also unclear whether the Pu is adsorbed as Pu(V) or as a lower oxidation state such as Pu(IV). The similar K_d values for Pu(V) and Th(IV) found in batch tests with ERDA-6 brines (about 10^3 and $10^{3.4}$ ml/g) suggest that the Pu may be adsorbing as Pu(IV). We were never shown tomographic results of the Th(IV) column tests and resultant K_d values. If these tests were run at Th(IV) concentrations below saturation with Th(IV) solids, the test results could be used to estimate the K_d for Pu(IV) adsorption. Finally, as noted earlier, it is possible that K_d values for the important actinides could be obtained in a few months from accelerated intact core experiments performed in an ultracentrifuge.

I hope my comments and suggestions have been useful to you.

Yours truly,

Don Langmuir

Donald Langmuir, PhD

RLW 3/19

REPORT ON CHEMICAL RETARDATION DATA FOR CULEBRA AQUIFER

To: Environmental Evaluation Group (EEG)
7007 Wyoming Blvd, NE
Albuquerque, NM

From: Mark L. Brusseau

Date: 11 August 1997

I have reviewed the documents supplied to me before and during the July 30 meeting, and have considered the presentations and comments provided during the meeting. My comments and recommendations are presented below.

I. Analysis of Original EEG Concerns

1. Use of batch K_d data: EEG originally expressed concern with the use of K_d values determined from batch experiments for the field-scale modeling. The major question was the representativeness of batch K_d values for the field scale. It appears that at least some (the more recent) batch experiments were conducted under well defined and controlled conditions. The results obtained from these experiments may thus provide an accurate data set for evaluating the "sorptivity" of the specific radionuclides used in the experiments.

   However, there remains the basic question of whether or not K_d values obtained under static batch conditions are an accurate measure for dynamic field conditions. I do not believe that this question has been answered for the Culebra system. To help address this issue, I recommend that additional analyses be made of the column experiments (to be discussed in greater detail below).

2. Use of Oxidation State Analogy: EEG expressed concern with the use of the oxidation state analogy for estimating K_d values. This approach appears to have merit in some cases (when it is definitively conservative), but appears to have large uncertainty for other cases. It is not clear why batch experiments were not conducted for the most critical radionuclides. An opinion was expressed by a DOE employee that the K_d values for at least some of the unmeasured radionuclides could be measured relatively easily. I recommend that such experiments be conducted for as many of the critical radionuclides as is feasible.

3. Use of Uniform Distribution: EEG expressed concern with the use of an uniform distribution for representing the K_d data. The reasoning provided by DOE for the use of an uniform distribution appears to be valid. As they noted, the experiments were not designed to provide a statistically representative sample of all possible field conditions. Thus, the uniform distribution should be the one to use. I recommend that this approach be accepted.

4. <u>Organic Ligands and Facilitated Transport</u>: EEG expressed concern regarding the potential of organic ligands to complex the radionuclides and thereby facilitate their transport. There were three subconcerns associated with this topic--

A) There was concern regarding the varied sources of complexation-coefficient data used in the original DOE analyses. The DOE mentioned new data at the meeting that may negate this concern. The DOE now appears to have a consistent set of measured complexation-coefficient data specific to the Culebra/WIPP system.

B) There was concern regarding the amount of EDTA DOE assumed would be present in the waste. I agree that there is great uncertainty in the concentration of EDTA that may be present in the WIPP system, and that the value used by DOE may be too small.

C) There was concern regarding the potential for other organic ligands, which were not included in the DOE analysis, to facilitate the transport of radionuclides. I agree with this concern.

To help resolve both B and C, I recommend that the DOE conduct a formal sensitivity analysis of 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. Based on the preliminary analysis presented by DOE personnel at the meeting, it is quite possible that the results from this study will indicate that complexation by the organic ligands may have minimal impact on radionuclide behavior. A formal sensitivity analysis will provide greater confidence in the results.

5. <u>Other Concerns of EEG</u>: EEG expressed concern with the application of the Norwegian dolomite study results to the Culebra system, and with the use of different CO_2 concentrations in the batch experiments. After the meeting, EEG commented that these were of minor concern, and I concur.

II. Additional Concerns

1. <u>Potential Nonlinear Sorption</u>: The data I reviewed indicates that the sorption of many of the radionuclides is most likely nonlinear. This is to be expected given the sorption mechanism stated by DOE (exchange reaction). As is well known, nonlinear sorption can cause retardation to vary as a function of solute concentration. In addition, it is possible that the initial representative retardation factor operative during field-scale transport may not be the same as that calculated using the batch K_d data. Thus, not accounting for nonlinear sorption may under or over predict retardation, depending on the initial solute concentrations used in the analyses. It is not clear if the range of K_d values reported by DOE take into account the concentration dependency of sorption. I recommend that the potential impact of nonlinear sorption be addressed.

2. Use of a K_d Approach versus a more Complex Approach: The transport model used by DOE is based on the simple K_d approach, which is based on linear, instantaneous sorption. It is clear that the fluid-solid interactions influencing radionuclide transport at the WIPP site are more complex, potentially involving inorganic/organic complexation, precipitation/dissolution, competitive sorption, and varying pH and ionic strength effects. The simplicity of the K_d approach makes its use understandable. However, some analysis of the potential impacts of more complex fluid-solid interactions on radionuclide transport would be useful.

3. Spatial Variability of Sorption: The current modelling analysis is based on a homogeneous K_d field. It is highly likely, however, that sorption is spatially variable at the site. The potential impact of spatially variable sorption on radionuclide transport should be evaluated.

III. Conclusions and Recommendations

Several questions and concerns were addressed satisfactorily at the meeting. However, some issues remained unresolved. The majority of these could potentially be resolved with relatively minimal additional effort. Recommendations for additional activities are as follows:

1. It is recommended that additional analyses be made of the column experiments. This includes additional analysis of the completed experiments and additional analysis of the ongoing experiments. The latter should involve an attempt to determine if precipitation is occurring during the column experiments, which appears to be a major uncertainty influencing the applicability of the column results. Would it be possible to sample the column material at the completion of the experiment and analyze for precipitated forms of the radionuclides?

2. I recommend that additional batch experiments be conducted to measured K_d values for the critical radionuclides, at least Pu^{III} and Pu^{IV}.

3. I recommend that a formal sensitivity analysis be conducted 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.

4. If the potential impact of nonlinear sorption is not incorporated in the range of K_d values used by DOE, I recommend that the potential impact of nonlinear sorption on radionuclide transport be addressed. This could be accomplished by calculating effective K_d values for pertinent C_o values, using the nonlinear isotherm data available. These values could then be compared to the existing K_d range.

5. I recommend that the potential impact of spatially variable sorption on radionuclide transport be evaluated. This could be done by conducting a series of model simulations using spatial distributions of K_ds based on the conceptual site models.

Leslie Smith
Hydrogeological Analysis • Groundwater Contamination Studies

August 12, 1997

Dr. Robert Neill
Director
Environmental Evaluation Group
7007 Wyoming Blvd, N.E., Suite F-2
Albuquerque, New Mexico 87109

Dear Bob,

In this letter I provide my viewpoint on chemical retardation in the Culebra dolomite. The opinions expressed reflect my consideration of the reports and correspondence supplied to me prior to the meeting, the material presented by EEG and DOE at our meeting on July 31, and the ensuing discussions that day. I will not comment directly on the issues concerning the amount of EDTA in the waste inventory, the potential for EDTA to facilitate transport of thorium, or the data presented by DOE to justify their application of the oxidation state analogy.

The Probability Distribution for Kd

I accept the DOE position that it is appropriate to adopt a uniform probability distribution to represent the uncertainty in the Kd values for the CCA calculations. The use of a log-uniform distribution, as required of DOE in the EPA verification tests, has the primary benefit of placing considerably more weight on the lower end of the proposed range for Kd. The EPA verification test suggests that the conclusions drawn from the CCA calculations with respect to transport in the Culebra are not sensitive to this marked change in the form of the distribution.

The probability distribution for Kd can be interpreted in terms of the likelihood that a value sampled from the distribution will correspond to an effective Kd value for sorption in the matrix blocks. This value must be applicable for transport times greater than 100 years, and transport distances of approximately 3 km. I see the attempt to quantify this likelihood as an issue related to, but distinct from, the distribution of Kd values obtained in the replicate batch tests. It is not feasible to obtain a set of field data, applicable at the scale of the transport predictions, that would allow one to equate the distribution of measurements with an appropriate sampling distribution in the CCA. One is forced to adopt a more subjective viewpoint in representing the uncertainty in the Kd value, with the consequence that the distribution of the data from the batch tests need not correspond to the distribution describing the likelihood for the effective Kd value. This approach is the most reasonable way to account for the spatial variability in Kd, and the influences of brine type and pH conditions inside a plume migrating through the Culebra.

4640 Mahood Drive, Richmond, British Columbia, Canada V7E 5C4
Office: (604) 822 4108 Fax: (604) 822 6088 Home: (604) 271 2799

The position taken by DOE that the sorption experiments (batch, mechanistic, and column tests) should be used to define a range for the Kd parameters, rather than its distribution in probability space, is reasonable.

I have used decision models that adopt uniform distributions to characterize the uncertainty in the key model parameters (eg. Bugai, Smith, Beckie; Environmental and Engineering Geoscience, 1996). We took this approach because we were faced with a sparse data base, and there were confounding uncertainties in future system behavior. A uniform distribution is appropriate when there is no strong basis for deciding if one value in the range is more likely than any other. It is my opinion that this is the case we face when selecting an effective Kd value for radionuclide transport in the Culebra. This is a slightly different spin on the DOE statement that "the uniform distribution is appropriate when all that is known about a parameter is its range".

In more recent work, I have adopted truncated exponential distributions to represent uncertainty in model parameters (Smith and Gaganis, Environmental and Engineering Geoscience, submitted). This latter model for representing parameter likelihood includes the uniform distribution as a special case, if the prior estimate of the mean is midway between the specified lower and upper bounds of the distribution. There is a sound basis in theory for choosing a truncated exponential distribution to represent parameter uncertainty, when the data base is sparse. Qualitatively, the log-uniform distribution is similar to the truncated exponential distribution, when the estimate of the mean is closer to the lower bound than the upper bound.

The more important issue to debate, in my opinion, is the values that DOE has selected 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. I agree with the approach taken by DOE in choosing a range for Kd relative to brine type that will give a conservative estimate of retardation. I was somewhat bothered by DOE's decision to select this range based on the average value of the sample distribution. It is possible to criticize the sampling range for Pu^{V} in this regard (and by their extrapolation, the sampling ranges for Pu^{III} and Am^{III}). The recommended range used in the CCA calculations was 20 - 500 ml/g, which reflects values from the batch tests using deep brines. Batch tests for Pu^{V} with Culebra brines had a higher mean value for Kd, but the lower bound was smaller (9.8 ml/g). Therefore, the sampling distribution in the CCA does not encompass all the measured values from the batch tests for a Culebra brine, at the low end of possible values. A more conservative sampling distribution would have ranged from 10 - 500 ml/g. However, because I would not expect the lowest value from a set of small-scale batch tests to equal the lower bound for a single, effective Kd value along a 3 km flow path, the consequence of their approximation is not likely to have a significant impact on the reliability of the CCA calculations. The analogy here is that the smallest value of hydraulic conductivity measured in a set of slug tests is not a reasonable lower bound on the estimate of a larger-scale effective hydraulic conductivity. A similar approximation did not emerge in selecting the sampling range for Th^{IV} because data are only available for the deep brine.

The DOE data base indicates U^{VI} will be the most mobile radionuclide of concern in the Culebra. The low end of the sampling range for U^{VI} is 0.03 ml/g, if we ignore the negative Kd values. This lower bound is obtained from the observed breakthrough of U^{VI} in the column tests. If we accept the interpretation of Bob Holt that the column test for U^{VI} measures retardation tied to the advective porosity, then this lower bound should be a conservative value for the compliance calculations when matrix diffusion plays a major role in retardation. The value from the column test is lower than any of the values in the batch tests (Tables D-1 through D-4 of the Brush memo, June 10, 1996). This sampling range for U^{VI} introduces the possibility that the EPA standard could be violated in an undetermined number of observations in the CCA calculations, if alternate scenarios were considered for the release of the uranium inventory from a disposal panel (ie. a Kd less than 1 ml/g, using the DOE benchmark for Pu^{III} and Am^{III}). We do not know how robust the CCA calculations are to a violation of the assumptions on the uranium release to the Culebra. Several factors need to be considered. A lower bound for Kd more reflective of matrix sorption than the value obtained in the column tests is not well-defined because of uncertainties in the batch tests (eg. the negative values). The zero values assigned to the negative Kd values for the batch tests with the Culebra brine did not get passed into the CCA calculation because of a lower average value of Kd for the batch tests using deep brines. This issue may be worth pursuing if EEG has concerns about the scenario assumed in characterizing the release of uranium to the Culebra.

An alternate interpretation in adopting the log-uniform distribution is that it de-emphasizes the importance of the Kd value that defines the upper bound of the distribution. Given the results of the EPA verification test, I have concluded that the questions regarding the relevance of the mechanistic Kd tests on pure dolomite from Norway are not a significant issue. These tests only make their way into the final sampling distributions once, in determining the upper bound for U^{VI} at high pH conditions.

The Sparse Kd Data Base

I disagree with the characterization made by M. McFadden in his opening presentation that Kd values used in the CCA are well-founded on experimental data. This simply is not the case, given the lack of experimental data for some radionuclides. The real issue is whether there is an adequate data base, and evidence to support the application of the oxidation state analogy, in assigning conservative bounds for radionuclides where measurement are not available from batch or column experiments. While I found the arguments presented by DOE to be compelling, they are not based on experimental data specific to the Culebra. It is still reasonable to ask if it would be more expedient, in a project of this magnitude and duration, and given the importance to DOE of a public demonstration of their commitment to ensuring the safe disposal of radioactive wastes, to complete a set of batch experiments on Pu^{III}, Am^{III}, and Pu^{IV}. DOE could then avoid the arguments and indirect support that must be linked to the oxidation state analogy. I understand for informal comments made at our meeting that these experiments could be carried out without great technical difficulty. My expectation from all that I have heard is that these tests would serve to confirm that DOE has used a suitable range of values in the CCA calculations.

Batch Tests

EEG has accepted the viewpoint that the batch tests have relevance in determining Kd values for the CCA calculations. After considering the geologic and hydrologic descriptions in the report by Bob Holt on a conceptual model for multi-rate transport in the Culebra, I am persuaded the batch tests can provide a basis for defining Kd values that characterize matrix sorption. The approach is subject to uncertainty (which should be balanced by conservative approximation), and I would not necessarily expect a one-to-one correspondence between a batch test and a long-term column test in a core from the same sample location (and interpreted with a dual porosity model). However, I am now of the opinion that the batch tests can be used to identify the sampling range in the CCA calculations. This sampling range applies only to the matrix porosity. It is inappropriate to use these batch test values to characterize retardation in the fracture system (advective porosity).

Column Tests

It is my impression that the latest analyses of the column tests do not move us much further along in reducing the uncertainty in the appropriate sampling range of Kd for Pu^{III} and Am^{III}. The attempt was worthwhile, but we now see there are limitations in the experimental design, because of issues tied to solubility. I agree that if it is technically feasible, it would be worthwhile to request that DOE try to determine if a mineral phase is present, that would confirm if the migration distance cannot be interpreted strictly in terms of a Kd estimate. It is not apparent to me what else could be done with the column experiments to gain further insight to the magnitude of Kd for Pu^{III} and Am^{III}.

Tom Clemo has raised the important issue that the only batch test data available for Th^{IV} (and, by DOE extrapolation U^{IV} and Pu^{IV}) are for the ERDA-6 brine. His statistical analysis suggests that the mean Kd's measured in ERDA-6 brine are greater than the values determined using the other 3 brines. It is my understanding that the column tests on the B core were carried out using Culebra brine. The estimated Kd value from tomographic analysis on the B-core is reported to be approximately 400 ml/g. Although this value is lower than the sampling range from batch tests that was used in the CCA calculations (900-20,000 ml/g), the value is sufficiently beyond 1-3 ml/g (the DOE benchmark) to suggest that Th^{IV} will not be of concern. Whether this same conclusion can be drawn for Pu^{IV} and U^{IV} depends upon the acceptability of the oxidation state analogy in setting conservative bounding values for their sampling distributions.

Beyond 10,000 Years

In our discussion after the meeting with DOE, we considered whether the CCA calculations should be extended beyond the mandated 10,000 year time frame. This topic is akin to an issue of full disclosure. There has been considerable informed debate on the regulatory time frame, and the advantages / limitations of looking beyond 10,000 years. My personal bias, influenced by reviewing projects under Canadian regulations, is to base siting decisions on a 10,000 year time frame, but to examine system behavior from a more qualitative perspective over a longer time horizon. Perhaps there is a role to be played here by EEG, in representing the interests of the State of New Mexico. It could be informative to look at the probability of radionuclide release along the pathway through the Culebra for time frames of 20,000 or 30,000 years, using the sampling distributions adopted by DOE.

Closure

EEG should continue to press DOE to refine and verify their calculations and modeling assumptions used in the CCA. Comments made by Sandia and LANL staff at the meeting suggest that this process is ongoing, if informal. For example, Vann Bynum described his latest calculations on the effects of the amounts of organic ligands on transport, and we heard that measurements of the EDTA β for nickel under WIPP conditions have recently been completed. Efforts to update the performance assessment should continue as time and computational tools become available.

Sincerely,

Leslie Smith

Leslie Smith

8.7 Walter Gerstles' Responses to Anhydrite Fracturing Issues Raised on February 17, 1998

Memo Feb. 24, 1998

To: Lokesh Chaturvedi
Environmental Evaluation Group
Albuquerque, NM
Fax: (505) 828-1062
Phone: (505) 828-1003

From: Walter Gerstle
Dept. of Civil Engineering
University of New Mexico
Albuquerque, NM 87131

I have had a few days to digest Norm Warpinski's presentation at our meeting last week. I make the following observations.

I. Estimate of Crack Opening Displacements in Bragflo Model

The Bragflo model "smears" cracks in the anhydrite layers, using the porosity model. Assuming 200,00 m^3 of gas is stored in these cracks, and assuming n layered cracks, with radius R=1000 m, it is possible to calculate the average crack opening displacement, w. Figure 1 shows the situation.

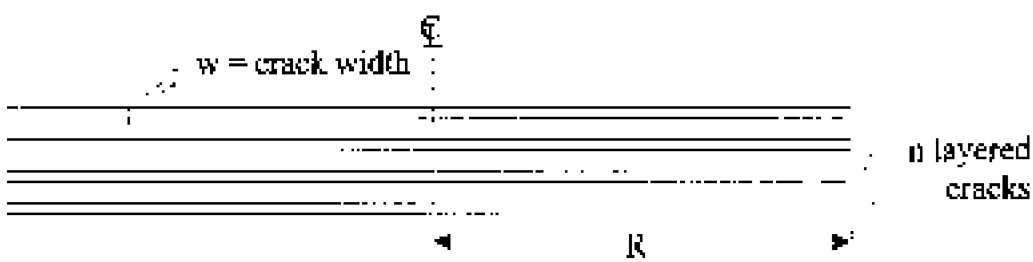


Figure 1. Cross Section Along Crack Diameter

The area, A, of each crack is $A = \pi R^2 = \pi(1000\ m)^2 = 3.14 \times 10^6\ m^2$.

$$olume = V = nwA;\ w = \frac{V}{nA} = \frac{200{,}000m^3}{n(3.14\times10^6 m^2)} = \frac{6.37cm}{n}$$

So the average crack opening displacement is 6.37 cm divided by the number of layered cracks.

The following table shows the average crack width for various numbers of cracks.

n	w, cm.
1	6.37
5	1.27
10	0.64
20	0.32

So the consequence of the Bragflo porosity model is many cracks with wide openings. However, anhydrite is relatively fine grained, and certainly cannot transmit stresses across crack openings of larger than approximately 0.001 cm. Consequently, it is reasonable to assume that all but one of the cracks would close up, but that single crack would extend in radius, as both the Gerstle and Bredehoeft 1997 and the Geertsma and Deklerk 1969 models assume.

II. Geertsma and Deklerk 1969 "Industry" Model

Warpinski made reference to the Geertsma and Deklerk 1969 model as being both an industry standard model and as being more consistent with the Bragflo model than with the LEFM model. In fact, the Geertsma and Deklerk model is an LEFM model, with fracture toughness assumed to be negligible, and it predicts even longer crack radii than the Gerstle and Bredehoeft 1997 model, contrary to Warpinski's assertions. I agree with Warpinski that the Geertsma and Deklerk model is basically reasonable, in that it assumes a single, localized, discrete crack.

A quote from Geertsma and Deklerk 1969 illustrates the fundamental difference between this model and the Bragflo model: "it is found that p_w (pressure at the well bore) decreases with increasing fracture length and approaches S (overburden stress) for large values of L (crack length). Such pressure behavior is in agreement with reported field observations." It is noted that the Gerstle and Bredehoeft 1997 model also demonstrates this pressure behavior, while the Bragflo model demonstrates the opposite pressure - crack length behavior. The decreasing pressure vs increasing crack length behavior also is indicative of a single, localized hydrofracture, which is in contrast with Bragflo's assumption of widely dispersed cracks forming simultaneously in multiple anhydrite layers.

Warpinski in his presentation predicted a crack radius of R = 366 m using Geertsma and Deklerk's formula:

$$R = \frac{1}{\pi}\left[\frac{Q^2 t}{C^2}\right]^{1/4} \qquad (24)$$

Where R = fracture radius
Q = rate of flow into hydrofracture
t = time
C = fracturing fluid coefficient, $C = u\sqrt{\Delta t}$
U = rate of filtration loss per unit of exposed surface of the fracture.

I do not know what numbers Warpinski used, but I used the following numbers and arrived at a much larger predicted radius, R.

$$u = \frac{4499 m^3}{2\pi(750 m)^2(1000 yrs)} = 1.27\times10^{-6}\ \frac{m^3}{m^2-yr.}$$

$$C = u\sqrt{\Delta t} = 1.26\times10^{-6}\frac{m^3}{m^2-yr} \times \sqrt{1000 yr} = 4\times10^{-5}\frac{m^3}{m^2-\sqrt{yr}}$$

$$Q = \frac{200{,}000 m^3}{1000 yrs} = 200 m^3/yr.$$

$$So \quad R = \frac{1}{\pi}\left[\frac{(200 m^3/yr)^2(1000 yr)}{(4\times10^{-5}\ m^3/m^2-\sqrt{yr})^2}\right]^{1/4} = 4003\ m.$$

Obviously, there is room for debate upon precisely what values of C, Q, and t are reasonable, but Sandia has not performed any calculations using the Geertsma and Deklerk model or any other standard hydrofracture model. This should be done.

III. Warpinski's claim that Gerstle and Bredehoeft model is incorrect

Warpinski claimed that Gerstle and Bredehoeft's 1997 model is incorrect because it contained no explicit flow equation and no leakoff equation. In fact, calculations in (Gerstle, Mendenhall, and Wawcisik 1996) show that leakoff is negligible - and therefore does not need to be explicitly included in the LEFM model. Warpinski also claimed that our model would require flow rates of $Q = 1.85 \times 10^{6}$ m^3/yr, using the equation

$$Q = \frac{\pi}{6\mu} \frac{w^3 \Delta P}{\ln\ [R/r]}$$

In fact, use of this equation is inappropriate because we assumed identical pressure ($\Delta P=0$) everywhere within the crack, and thus flow Q would be negligible. Our LEFM model neither assumes nor requires high flow rates.

IV. Conclusions

It is essential for the WIPP facility that a credible gas-driven hydrofracture model be used. I believe that the (Gerstle and Bredehoeft 1997) model is essentially correct despite Warpinski's observations about it. Warpinski's comments appear to be spurious.

I would suggest that Sandia present calculations of hydrofracture extent using Geertsma and Deklerk 1969 model, fully documenting all inputs to the model. I believe they will arrive at conclusions similar to those I have presented.

8.8 Neill to Kruger letter dated 8/11/97 with attachment, "EEG comments on CCA Chapter 5"

ENVIRONMENTAL EVALUATION GROUP

COPY

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003
FAX (505) 828-1062

August 11, 1997

Mary Kruger
U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
401 M Street SW (6602J)
Washington, DC 20460

Dear Ms. Kruger:

Enclosed please find the *EEG Review of the WIPP/CCA (DOE/CAO-1996-2184), Chapter 5 (Quality Assurance).*

Sincerely,

Bob

Robert H. Neill
Director

RHN:js

cc: EPA Docket

EEG REVIEW OF WIPP/CCA (DOE/CAO-1996-2184)
CHAPTER 5 (QUALITY ASSURANCE)

The DOE's Carlsbad Area Office (CAO) has successfully focused on developing a quality assurance (QA) program which implements the Nuclear Quality Assurance (NQA) standards required by 40 CFR 194 over the last few years. Chapter 5, Quality Assurance (QA), in the DOE's Compliance Certification Application (CCA), is, however, of lesser quality than the QA program it attempts to describe. The chapter fails to show compliance with most of the requirements of 40 CFR 194.22, Quality Assurance, and ignores most of the expectations for QA published in EPA 402-R-95-014, Compliance Application Guidance for 40 CFR 194 (the CAG).

In a chapter which should provide specific responses to clearly delineated requirements and expectations Chapter 5 offers a diffuse scattering of relevant information, provides generalized information without examples or details, and references other documents which are no more specific (and were not intended to address the QA requirements for the CCA). The chapter contains what seems to be extraneous information (some of which is found elsewhere in the CCA), glosses over past QA problems rather than explaining how they were resolved, and fails to include information explicitly required by 40 CFR 194.22. In many cases the CAO QA program and process has adequately covered the area, yet the chapter fails to fulfill the responsibility of describing how it was done.

Parts of Chapter 5 are also misleading. For example, "the CAO QAPD" is referenced throughout much of the chapter and is initially identified as appearing in CCA Appendix QAPD. The version in the Appendix QAPD is Revision 1, dated April 22, 1996, though it was not officially transmitted to, or required to be implemented by, subsidiary organizations until after June 13, 1996--when essentially all QA-related activities for the CCA had already been completed. Revision 1 is a substantial rewrite of Revision 0, among other things establishing the CAO QAPD as a requirements document for all CAO subsidiary programs for the first time, and adding elements of NQA standards previously not included. To state that

> The TWBIR was prepared in compliance with the CAO QAPD...

(p. 5-3) implies that the data from the TWBIR used in the CCA (first published in December 1995) was prepared according to the requirements in Revision 1. It wasn't, and the distinction should have been clearly made. Similar statements are found elsewhere Chapter 5:

> The WAC was written and reviewed in compliance with the CAO QAPD [p. 5-3]...The TRU QAPP was written and reviewed in compliance with the CAO QAPD requirements [p. 5-4]...NDA software is controlled in accordance with the requirements of the CAO QAPD [p. 5-9]...

Versions of the WAC and TRU QAPP current at the time the CCA was submitted were written under Revision 0; the NDA (Non-Destructive Assay) software is, of course, currently controlled under Revision 1, but any NDA data used in the CCA would clearly predate the issuance of Revision 1.

The chapter contains an important misinterpretation of the intent of 40 CFR 194.22(a)(2). This paragraph requires the compliance application to demonstrate that a QA program adhering to the 1989 edition of the Nuclear Quality Assurance (NQA) standards has been established and executed for eight specific areas considered by the EPA to be critical to the compliance application. In Chapter 5, this is interpreted (p. 5-3, line 28) as:

> 40 CFR Part 194 stipulates that the DOE apply QA controls to eight areas.

Under this interpretation Chapter 5 fails to clearly demonstrate that the requirements of the NQA standards have been executed for any of the eight areas, though discussions under specific headings for each of the eight areas immediately follows. In some of these discussions virtually no QA information is supplied at all.

The EEG, in a preliminary commentary (Neill-to-Dials letter dated July 22, 1996; see Attachment I) on what now must be considered a draft of the final Chapter 5, pointed out several clearly erroneous statements in the text. Most of these have been removed from this October version, but the chapter still includes a curious concept that since the EPA had reviewed site selection and site characterization QA programs during examination of the 1989 No-Migration Variance Petition (NMVP), the QA for site selection and characterization is considered satisfactory by the DOE (p. 5-8). The EEG's comment pointed out that the argument was untenable, in that (among other reasons) compliance with NQA standards was not a part of the 1989 NMVP. The DOE response (enclosure to undated Dials-to-Neill letter received August 9, 1996; see Attachment II, enclosure p. 4) stated that the DOE agreed with the comment, and "We have updated this portion of Chapter 5". The updating is not apparent--the argument is still the same, and still an obvious error (see line-by-line review of p. 5-6, lines 6-13 for more discussion).

The EEG's July 1996 letter concerning Chapter 5 (see Attachment I) recommended that the DOE rewrite the chapter to meet the published EPA requirements and expectations for QA. The DOE has not substantially rewritten the document (though material was added and removed), and this final CCA Chapter 5 and associated materials arguably fails to demonstrate fulfillment of the requirements in 40 CFR 194.22, Quality Assurance.

The following sections consist of 1) a comparison of Chapter 5 to the CAG expectations; 2) a comparison of Chapter 5 to the requirements for QA in 40 CFR 194.22; and 3) a line-by-line review of the document.

OCTOBER '96 CCA CHAPTER 5 (QA) AND THE CAG

The DOE has previously (see Attachment II, letter p. 2, and enclosure p. 7) informed the EEG that, as a guidance document, the Compliance Application Guidance (CAG) expectations need not necessarily be included in the CCA. However, the CCA begins with the statement that:

> This application has been developed to be fully responsive to the requirements of 40 CFR Part 191, the criteria in 40 CFR Part 194, and the guidance in the *Compliance Application Guidance for 40 CFR Part 194*, EPA 402-R-95-014. [p. EXEC-1;

emphasis in the original]

Chapter 5 is not fully responsive to the CAG expectations. The chapter seems to address the CAG requirements for QA only occasionally, and by accident, rather than design. Below are listed some of the CAG expectations for §194.22, Quality Assurance, and the results of EEG's attempts to find the data in Chapter 5. This is not an exhaustive list, as it is intended only to show that the CAG expectations for QA were not addressed by the DOE.

CAG §194.22(a)(1) Expectations (p. 18 of CAG):

1. *DOE top tier QA documents will be included in the CCA.*

   The DOE included only the CAO QAPD. The TRU Waste Characterization Quality Assurance Program Plan, Revision 0 (QAPP; CAO-94-1010) would also seem to be a DOE top-tier document, and much of it would enhance the DOE's claim to having implemented a QA program in accordance with the NQA statutes. The TRU-Waste Characterization QAPP (Section 1.0, p. 1.1) does contain an important statement that the CAO QAPD Revision 1 lacks:

   > This QAPP addresses all of the basic requirements, and their supplements, of ASME NQA-1.

   Section 1.9.3, Computer Hardware and Software, of the Waste Characterization QAPP also supplies a clear statement requiring the use of the successor document to the 1989 NQA-2 Subpart 2.7, "Quality Assurance Requirements of Computer Software for Nuclear Facility Applications", which would seem to address the specifications for software QA as required by 40 CFR 194.22(a)(1). The CAO QAPD Revision 1 contains no comparable direct statement of compliance with the requirements found in §194.22(a)(1)--that is, adherence to a QA program which implements the requirements of NQA-1, NQA-2 Part 2.7, and NQA-3.

   Nor, in fact, does Chapter 5 contain a direct statement of compliance to the requirements of NQA-1, NQA-2 Part 2.7, or NQA-3.

2. *DOE principal contractor top tier QA documents, and a list of all non-principal contractor or sub-contractor top tier QA documents will be included in the CCA.*

   SNL QA top-tier documents were not included, nor any listing of QA documents for non-principal contractors or subcontractors for WID or SNL.

CAG §194.22(a)(2) expectations are that, for each of 8 defined critical areas, the CCA will (among many other expectations):

1. *Provide a list of quality affecting activities and items important to a demonstration of compliance.*

   Lists seem to be incomplete. For instance, the bulk of field measurements of geological factors were performed by SNL, yet SNL activities are described as "None" in the section concerning measurement of geological factors (5.1.3; p. 5-6, line 26). Other examples: Section 5.1.1 identifies the WIPP Waste Information System (WWIS; p. 5-4, lines 2-3) and the Performance Demonstration Program PDP (p. 5-4, lines 22-23) as elements of the waste characterization system, but doesn't show them as activity for any of the organizations involved. Section 5.1.2 doesn't include a discussion of QA on the current WID environmental monitoring program; Section 5.1.3 doesn't mention QA of the current WID meteorological monitoring program, or past SNL meteorological programs. These two sections have "environmental monitoring" and "meteorological" in their titles.

2. *Describe the selection of applicable NQA requirements for each of the areas.*

   No descriptions are included.

3. *Provide dates of QA implementation conforming to NQA for each item or activity, and the nature and location of objective evidence which supports this determination.*

   No dates are provided.

CAG §194.22(b) expectation (other expectations were also not met, though some were met in part):

1. *Provide the QED governing documents that include procedures and management plans for independent review, peer review...*

   QED governing documents were not included in the CCA (CAO MP 10.5, SNL QAP 20-3).

OCTOBER '96 CCA CHAPTER 5 (QA) AND §194.22 REQUIREMENTS

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

The CAO QAPD Revision 1 (in CCA Appendix QAPD) does not require full implementation of NQA standards for all activities, but only for those listed in §194.22(a)(2), other radioactive materials handling, and processes related to transportation containers. This is established in the CAO QAPD in section 1.1.2.3, Applicability of QAPD Requirements, where the difference between general requirements and additional requirements is introduced, and subsections A through J list the areas that fall under the additional requirements. The additional requirements generally seem to be those which are found in the NQA standards, but not in DOE Order 5700.6C, the DOE's internal QA requirements document (which follows 10 CFR 830.120). For compliance with 40 CFR 194.22(a)(1), the NQA standards may need to be the primary criteria.

There is no indication in §194.22(a)(1), or anywhere else in the criteria, that some WIPP activities can be granted a variance from the requirements of the NQA standards.

§194.22(a)(2) Requirement: *The compliance application will demonstrate that the QA program adhering to the NQA standards has been established and executed for the following activities: waste (i) characterization activities and assumptions; (ii) environmental monitoring, monitoring of the disposal system performance, and sampling and analysis activities; (iii) field measurements of geologic factors, ground water, meteorologic, and topographic characteristics; (iv) computations, computer codes, models and methods used to demonstrate compliance; (v) expert elicitation procedures used to support compliance; (vi) design of the disposal system and actions taken to ensure compliance with design specifications; (vii) collection of data used to support the compliance application; (vii) other systems structures, components, and activities important to containment of waste .*

The requirement is misinterpreted in Chapter 5 as "40 CFR 194 stipulates that the DOE apply QA controls to eight areas" (p. 5-3, line 28). The misinterpretation is essentially an echo of page 5-2, lines 6 and 7. This statement is far from presenting evidence that the program has been established and executed. Demonstration of execution would presumably be by citing independent assessments (audits and surveillances) for the different areas.

The chapter does provide separate sections for each of the eight activities, but demonstration of establishment and execution of adherence to the NQA standard requirements is weak or nonexistent in these sections and references from these sections (see line-by-line review below).

§194.22(b) Requirement: *The compliance application shall include information which demonstrates that data collected prior to establishment of adherence to the NQA standards has been qualified by a methodology approved by the EPA.*

Chapter 5 offers no demonstration of EPA approval of any of the methods used. While the EEG understands that the EPA has not provided approval/disapproval to the DOE for the various methods the DOE has utilized, §194.22(b) clearly requires information demonstrating approval to be in the CCA. The CCA should at least contain a statement concerning qualification of the methodology by the EPA.

§194.22(c) Requirement: *The compliance application shall provide, to the extent practicable, information which describes how data in support of the application have been assessed for data quality characteristics, including precision, accuracy, representativeness, completeness, and comparability (PARCC).*

The application provides an argument that it is not practicable to apply the PARCC characteristics to "most scientific investigations used to support performance assessment in which there is uncertainty in conceptual models and the resultant ranges of parameters" (section 5.21.1, lines 40-42). The characteristics are not provided as required. While it may be that evaluation of these characteristics did not take place at the sampling level, some assessment should have been made to establish how much uncertainty in models and parameters would be not only practicable, but necessary. Note also that apparently some of the scientific investigations are not covered by the argument, and information which describes how PARCC was assessed for these, at least, should have been included. For example, the argument states specifically that the PARCC requirements would apply to waste characterization and environmental monitoring activities, yet provides no information as to how data from these areas were assessed for PARCC.

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

Section 5.4.2.1 of the CCA does provide a description of the programs for qualifying data.

LINE-BY-LINE REVIEW OF CHAPTER 5

Introductory Material

Page 5-1, Lines 17-18: *...see Table 1-5 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter...*

Table 1-5 lists only Appendices QAPP and AUD, but other appendices are referenced in Chapter 5 (MON, p. 5-5 line 38; EMP, p. 5-6 line 20); SEAL, p. 5-12 line 24)

These additional appendices should have been included in Table 1-5.

Page 5-1, Lines 29-31: *A comprehensive series of assessments has determined that the DOE, SNL, and WID QA programs are adequate and effectively implemented.*

The overall CAO assessment of SNL QA (May 1996) and WID QA (June 1997) previous to the publishing of the CCA found the SNL program to be marginal both for adequacy and implementation, and the WID program marginally effective (see CCA p. 5-39, lines 6-13 for definitions of these terms.). It is the later resolution of issues raised during the assessment by which the CAO determined SNL and WID QA to be adequate and effectively implemented (see Section 5.4.2, p. 5-45 ff, and section 5.4.3, lines 24-29). The text of this portion of Chapter 5 should reflect that the resolution of concerns raised by the assessments were performed before the SNL and WID QA programs was determined to be adequate and effectively implemented.

<u>5.1. Applicability</u>

Page 5-2, Line 6: *These NQA requirements form the basis of the CAO QAPD.*

Revision 1 of the CAO QAPD may incorporate the requirements in the NQA standards, but they are split between general requirements (for all activities) and additional requirements (applied to activities in which radioactive materials, shipping packages, or the eight compliance activities specified by §194.22(a)(2) are involved). This division indicates that DOE Order 5700.6C is the basis of the CAO QAPD rather than the NQA requirements, as DOE Order 5700.6C is covered by the general requirements, and the additional requirements are those NQA requirements not covered in the DOE Order.

There is no variance granted in §194.22(a)(1) for activities in the QA program, and Chapter 5 presents no evidence of any agreement for such a variance. The intent of the regulation seems to be that the WIPP will adhere to NQA standards for at least all disposal-related activities, and arguably for the entire QA program.

This statement is, however, as close as Chapter 5 gets to a clear statement of compliance with §194.22(a)(1), which requires that the DOE

> ...shall adhere to a quality assurance program that implements the requirements of [the NQA standards].

Page 5-2, Lines 6-7: *Additionally, 40 CFR § 194.22 requires that QA programs be applied to the following eight items or activities:...*

§194.22(a)(2) does not require the application of QA programs to the areas described in its eight subparagraphs. The requirement is for the compliance application: the CCA must demonstrate that the requirements of the NQA standards have been applied for each of the eight subparagraphs. The regulation is:

> Any compliance application shall include information which demonstrates that the quality assurance program required pursuant to paragraph (a)(1) of this section has been established and executed for [the eight activities].

Demonstration of execution of the requirements of the NQA standards would presumably be by describing QA assessments which confirm adherence to the NQA standards for each of the areas.

The difference in approach to the requirement is critical. Chapter 5 describes the general QA program which includes the eight critical area specified by §194.22(a)(2), but is ineffective in demonstrating that the QA program has been established and executed for each of them.

This misinterpretation of the regulatory requirement is repeated on page 5-3, line 28 (see below). The chapter should address the requirements as stated.

Page 5-2, lines 33-39: *The CAO QAPD establishes two primary categories of requirements, identified as general requirements and additional requirements. The sections of the CAO QAPD that do not identify specific applications are general requirements that apply to all items, activities, and processes under the cognizance of the DOE. The requirements of the CAO QAPD sections identified as additional requirements apply to the eight key areas identified above.*

See comment for page 5-2, line 6. These statements imply that the NQA standards in the CAO QAPD Rev. 1 additional requirements are to be applied only to the eight key areas, omitting the radioactive materials handling and NRC packaging included in Revision 1 of the CAO QAPD (sections 1.1.2.3.A and 1.1.2.3.J; pp. 1-10 and 1-11).

Page 5-2, line 41, to page 5-3, line 8: *Additionally, the use of a graded approach supports the proper implementation of QA program requirements...*

The discussion of the graded approach offers no tie of the graded approach to the compliance application requirements. A statement that NQA-1 does allow the graded approach (with reference) would seem appropriate, and perhaps necessary.

40 CFR 194.22(a)(1) specifically excludes those portions of NQA-3 (which addresses QA for site characterization data collection activities), that refer to the graded approach. Having raised the "graded approach" issue, Chapter 5 should provide evidence (even a single statement) that the site characterization data was not collected or processed using a graded approach to QA.

Page 5-3, lines 11-14: *The CAO QAPD requirements are further supported and amplified by the next tier of QA program documents which include the DOE TRU Waste Characterization Quality Assurance Program Plan (TRU QAPP), the SNL Implementing Procedures, and the WID Quality Assurance Program Description.*

The first CAG expectation (p. 18) is that the DOE top tier QA documents be included in the application; the second is that the top tier QA documents of principle contractors also be included in the application. This first mention of these documents should also state where they can be found. CCA Appendix QAPP contains the CAO QAPD Rev. 1 and the WID QAPD Rev. 16, but the TRU QAPP, SNL's procedures, and QAPjPs from the generator sites are not included.

It is important to note that the CAO QAPD Revision 1 became the sole "top tier" DOE QA document after June 13, 1996 (the CAO transmittal letter dated June 13, 1996 requires it to be implemented within 60 days after receipt). There was no requisite condition previously that programs other than the CAO itself adhere to the CAO QAPD. Revision 0 states that the QA programs of WIPP participants are expected to be "guided" by the CAO QAPD only (p. 1-1), and the DOE has informed the EEG that guidance documents need not be followed (Neill-to-Dials letter received August 9, 1996).

Revision 0 also did not place an emphasis on the NQA standards as requirements for WIPP QA programs, instead stating that (p. 1-1):

> WIPP participants develop, implement, maintain, and document their quality assurance programs either in accordance with DOE Order 5700.6C or 10 CFR Part 830.

Page 5-3, line 28: *40 CFR Part 194 stipulates that the DOE apply QA controls to eight areas.*

The requirement (§194.22(a)(2) is that the compliance application demonstrate that a QA program adhering to the NQA standards has been established and executed for the eight areas (see comment for page 5-2, lines 6-7).

Section 5.1.1, Waste Characterization Activities and Assumptions

Page 5-3, lines 34-39: *The Transuranic Waste Baseline Inventory Report (TWBIR) (see Appendix BIR) is the inventory source document that provided the waste data used in the performance assessment and is presented in tabular form in Chapter 4.0...*

Chapter 5 is titled "Quality Assurance", but is noticeably incomplete in discussing QA for the TWBIR.

The TWBIR has been published separately as Revision 0 (June 1994), Revision 1 (February 1995), and Revision 2 (December 1995), and some of the radionuclide data varies widely between the different versions. CCA Appendix BIR data is from Revision 2, with additional material requested by the EPA after Revision 2 was published (included in TWBIR Revision 3, according to the Executive Summary).

None of the data in any of the TWBIR versions seems to have been gathered under the NQA standards as required by §194.22(a)(2)(i). Sources of information included extrapolations from, among other sources, safety documentation and interviews with workers (TWBIR 2 p. 1-21; DOE/CAO-95-1121). EEG-61, Review of the WIPP Draft Application To Show Compliance with EPA Transuranic Waste Disposal Standards (EEG; March, 1996) on page 4-5 quotes a 1995 ORNL report that "TRU waste streams at ORNL are not as yet fully characterized...waste sludge...physical data such as particle size, hardness, viscosity and particle distribution are unknown".

The bulk of the source data may be more reliable, but is based primarily on acceptable knowledge (TWBIR 2, p. 1-20), which is in turn predominantly process knowledge. Use of process knowledge to quantify components in waste, which is how the TWBIR data is used in the CCA, is required by §194.24(c)(3) to conform to the NQA standards, also. There is no evidence in the CCA that any of the process knowledge activities were conducted under the requirements of the NQA standards.

The Waste Characterization Analysis Peer Review Report (p. 4-3) mentions both cost and time restraints as justification for the lack of QA on the TWBIR. The NQA standards contain no variances for cost and time considerations.

Page 5-3, lines 36-38. *The TWBIR was prepared in compliance with the CAO QAPD and this activity was audited by the DOE QA Program on September 5 and 6, 1995.*

Chapter 5 is offering incomplete and misleading data here. Note that the data (taken from Revision 2) used for the CCA was published months after the single assessment (a surveillance by one auditor, not an audit) cited, and QA of the additional data requested by the EPA (in 1996) included in CCA TWBIR was certainly not assessed during the surveillance. The surveillance issued one significant finding, which essentially stated that there was no analysis or data collection plan to assess the TWBIR against, as is required by the NQA standards.

The implication is that the waste characterization data used in the CCA has not undergone sufficient QA assessment. Given that both §194.22(a)(2) and §194.24(c)(3) required a demonstration in the CCA that QA has been performed on the TWBIR data, it would seem that a QA assessment should have been conducted of the TWBIR data used in the CCA.

Page 5-3, lines 38-39: *Quality assurance of the use of these waste data (by SNL) for performance assessment is addressed in Sections 5.1.4 and 5.1.7.*

The referenced sections are brief generalized statements which include no specific discussion of waste characterization data from the TWBIR. The data in section 5.1.4 is, in fact, misleading when applied to TWBIR data--it does contain a brief paragraph on the use of NDA (non-destructive assay) QA, which in part states that:

> NDA software is controlled in accordance with the requirements of the CAO QAPD.

NDA software used to gather data in the TWBIR, Revision 2, was not controlled by the requirements of the CAO QAPD (see earlier discussion).

Page 5-3, line 41 - page 5-4, line 12: *The Waste Acceptance Criteria (WAC) serve as the primary directive for ensuring that only waste that can be transported, handled, and disposed of in the WIPP are shipped and or ensuring that these wastes are certified by the generator and storage sites....The TRU QAPP describes the QA and quality control requirements for characterization....*

The requirement from §194.22(a)(2) is for a demonstration that a QA program in conformance with the NQA standards has not only been established, but also executed for waste characterization activities. Presumably, demonstration of execution would be accomplished by citing QA assessment reports on the generator sites. The EEG is unaware of any demonstration that compliance with the WAC criteria has been officially met for any waste container, so it seems unlikely that the NQA requirements can be said to have been "executed".

It may be argued that establishing the QA of the WAC, the TRU QAPP, and site QAPjPs and procedures as documents shows that the NQA standards have been "executed". One counter to this argument is provided on page 4-9 of EEG-61 (cited above): 58% of a WAC-certified population of 80 drums at INEL were miscertified according to a 1993 DOE report (DOE/WIPP 93-062).

The DOE now has a strict program for certification of generator sites before waste characterization can take place. Information on a demonstration of a full execution of the requirements of the NQA standards at the generator sites, including the certification audits, should have been provided in the CCA.

Page 5-4 line 14-16: *The DOE verifies program implementation at participating sites through audits and assessments to ensure that WIPP waste characterization activities comply with* *applicable QAPjPs and standard operating procedures.*

The first three sites to ship waste to WIPP will be INEEL, Rocky Flats, and LANL. The three CAO formal assessments of waste characterization QA at these sites previous to CCA publication found that at INEEL (August 1995; INEL at the time), that ANL-W QA was inadequate; at Rocky Flats (September 1995), that the program was marginal; at LANL (August 1996), that software QA had only just begun. LANL waste characterization has not yet been formally audited by CAO to the NQA standards, though several surveillance-type activities have taken place. None of these would qualify as a demonstration that a QA program adhering to the requirements of the NQA standards had been established and executed for waste characterization activities and assumptions.

Page 5-4 Lines 25-42: *The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants. DOE Activities: ...DOE QA Documents: ...*

The list of documents does not include some that would seem to be applicable. For instance, documentation used in design of the TWBIR (which should have addressed QA), the TRU Waste Characterization QAPP, the WWIS Software Quality Assurance Plan, and Performance Demonstration Program documentation should be listed, as these activities are all mentioned in the preceding text.

The "examples of subcontractors for the principal participants" does not include the subcontractor that assembled the TWBIR, which is the principal waste characterization activity that had taken place at the time the CCA was published.

Page 5-5 Lines 3-25: *Generator Site Activities: 1. Characterize TRU waste. Generator Site QA Documents: The following sites have Generator Site QAPjPs that have been approved by the DOE...*

The DOE should show that the QAPjPs were in force for the collection of data for the TWBIR. It is likely that the approval of at least some of the QAPjPs by CAO post-dates the accumulation of the TWBIR data.

The CAG (Compliance Application Guidance for 40 CFR Part 194; EPA 402-R-95-014) states (p. 18-19) that the EPA expects much more information on waste characterization activities and assumptions than is included in this section. Among these expectations are several that relate to objective evidence for various QA activities; a listing of dates when conformation to the NQA standards for each activity became effective; a description of not only DOE but principal contractor QA assessment activities; and the schedules for these activities. None of these are supplied in the CCA, though Appendix AUD lists by title (which is not a description) and date a general list of assessments that includes CAO's waste characterization assessments. The list does not however, show assessments by "principal contractors", which for waste characterization would be the generator site QA programs.

Section 5.1.2 Environmental Monitoring, Monitoring of the Performance of the Disposal System, and Sampling and Analysis Activities.

Page 5-5, Lines 30-38: *The monitoring plans required by 40 CFR § 194.42 detail the disposal system monitoring program that will be implemented during pre-and postclosure of the WIPP. This program will be implemented by the WID under the QA program described in this chapter. SNL Activities: None. WID Activities: Conduct performance monitoring. WID Documents: Reference Appendices MON and EMP.*

Lines 30-38 are the complete section. The section offers no demonstration that the "monitoring plans" have been established in accordance with the NQA standards; the "monitoring plans" are not even identified, though one can infer that the appendices may contain them. The section itself offers no demonstration that a QA program adhering to the requirements of the NQA standards has been established and executed for the titular areas--no QA documents specific to the activities are listed, no procedures that would demonstrate QA requirements at the working level.

Environmental monitoring activities, and associated sampling and analyses activities, have been conducted for years by the WID but no mention is made of QA for this effort.

The referenced appendices do not contain information which demonstrates execution of the NQA standards, even for the pre-closure activities that have been in operation for years. The QA section in CCA Appendix MON simply states (p. MON-62) that future work will be controlled by the CAO QAPD Rev. 1, and that the DOE has "agreed to adopt QA and quality control guidance" from the NQA standards (the DOE opinion is that guidance for QA is not a requirement, and therefore need not be addressed). CCA Appendix EMP describes in general terms the QA program for environmental monitoring but does not demonstrate that it has been executed. The description is in terms of 10 CFR 830.120 (from which DOE Order 5700.6C was derived), not the NQA standards, though a table (Table 8-1 on p. 8-2) attempts a cross-reference to NQA-1 requirements.

The mapping of 10 CFR 830.120 or DOE Order 5700.6C requirements to the NQA standards is not a satisfactory process--nor a quality one. NQA-1 alone contains about 30 pages of basic and supplemental requirements (not counting definitions or suggested practices); the §830.120 requirements cover about 2 pages. To find 30 pages of requirements in 2 pages of information would seem to require an exceedingly imaginative approach.

It appears that 40 CFR 194.22(a)(2)(ii) requirement for demonstration in the CCA that a quality assurance program in conformance with the NQA standards has been established and executed for monitoring has at best only been partially met.

The CAG expectations seem to have been ignored completely, unless "conduct performance monitoring" can be considered a "list" of quality affecting activities.

Section 5.1.3 Field Measurements of Geological Factors, Groundwater, Meteorologic, and

Topographic Characteristics

Page 5-5, Lines 43 to page 5-6, line 4: *The current WIPP activities related to field measurements are conducted by the WID and include several areas. Measurements of geologic factors include...*

No statements related to QA are attached to the description of measurement of geological factors.

Page 5-6, lines 6-13: *In 1989, the EPA reviewed and commented on much of the data collected by the DOE during the site selection and site characterization program. After this review by EPA geologists, hydrologists, and other scientists, the EPA reached conclusions regarding the adequacy of the DOE's site characterization program and the reasonableness of the site characterization activities. The EPA's independent reviews and conclusions regarding the adequacy of the data were supplemented by the independent reviews conducted by the National Academy of Sciences. Therefore, the DOE considers the adequacy of the QA program and the data collected during site selection and characterization to be satisfactory.*

Substantially the same argument was included in the earlier version of Chapter 5 that EEG commented on (Neill to Dials letter dated July 13, 1996). The EEG comment (p. 3 of the enclosure) noted that:

> This is untenable on several grounds, not the least of which is that the NMVP is for compliance with 40 CFR 268.6, which has no requirement that QA programs must comply with the 1989 versions of NQA-1, NQA-2 Part 2.7, and NQA-3, as is found in 40 CFR 194.

The DOE's response (p. 4 of the enclosure to Dials-to-Neill letter received August 9, 1996) was as follows:

> We agree with the comment on the No Migration Variance Petition (NMVP) and had already noted this. We have updated this portion of Chapter 5.

The only substantive differences between the two presentations of the argument is that 1) in the most recent version, a statement that the EEG also conducted an independent review and was in agreement with the EPA and NAS conclusions has been dropped; and 2) references to the source document were dropped.

The argument is ludicrous in a document written to show compliance with 40 CFR 194. A large part of site characterization data included in the CCA has been performed since 1989; the NMVP is concerned with disposal of chemical wastes, not the radiological component that is the §194 concern, and the major concern at WIPP (plutonium is not on the list of 40 CFR 268 hazardous components); QA approaches and philosophies have changed in the intervening years; the regulation to be complied with is different for the CCA (40 CFR 191 and 194) than it was for the NMVP (40 CFR 268); and a demonstration of establishment and execution of a QA program that adheres to the NQA standards was not a requirement for the 1989 NMVP.

Neither the "References" nor the "Bibliography" at the end of Chapter 5 contain an entry for either an EPA document, or an NAS document, concerning the 1989 NMVP. The accuracy of the DOE interpretation cannot be verified without proper referencing of the source documents.

The May 31, 1996 draft of Chapter 5 (p. 5-6) included the statement that:

> These conclusions were issued in a document titled Background Document for the U.S. Environmental Protection Agency's Proposed Decision on the No-Migration Variance for the U.S. Department of Energy's Waste Isolation Pilot Plant.

No further information on this document was provided in the bibliography of the May 31, 1996 draft Chapter 5. One of the EEG's comments on this draft was that documents were not referenced in a manner which allowed traceability.

Page 5-6, lines 15 and 17: *Topographic characteristics were characterized early in the site characterization phase of the WIPP project, and the QA of data from that period is addressed in detail in Section 5.4.2.2.*

Section 5.4.2.2 discusses in very generalized terms the Qualification of Existing Data (QED) process (for data that was not collected under an NQA program) and includes no commentary specific to measurements of topographic characteristics. Reference to this section implies that a demonstration of adherence to NQA standards for topographic characteristics as required by §194.22(a)(2) cannot be performed.

Page 5-6, lines 20-21: *See Appendix EMP for QA controls applied to monitoring activities of groundwater well levels.*

The section of Appendix EMP concerning groundwater (Section 5.4.3, p. 5-12) does not include any QA information; the QA section of Appendix EMP does not discuss establishment and execution of NQA requirements (see comments to p. 5-5, lines 30-38 above for additional data on the QA section of Appendix EMP).

Page 5-6, lines 23-35: *The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants. SNL Activities: None.*

SNL was responsible for most of the measurements of geologic factors, including the "site selection and characterization program" mentioned in this section. To state that there were no SNL activities, QA documents, or subcontractors is ludicrous.

WID Activities:

No mention is made of the WID meteorological measurements or associated QA efforts.

The WID has measured meteorologic characteristics at the WIPP for many years; Section 2.5.2 (p. 2-178 ff) of the CCA indicates that data was used in the CCA from WID environmental monitoring reports from 1991-1995. This section of Chapter 5 should demonstrate that a QA program adhering to the requirements of the NQA standards was established and executed for these data and reports.

Appendix EMP also contains a section on meteorological monitoring (section 5.4.1, p. 5-11) which states that:

> A Quality Assurance Project Plan (QAPjP) is being developed for the collection of meteorological data use [sic] for regulatory purposes.

This QAPjP may be necessary before demonstration of establishment and execution of a quality assurance program that adheres to the NQA requirements can be made.

Appendix EMP section 5.4.1 lists the requirements documents for the QAPjP. Those listed do not include 40 CFR 194, the NQA standards, or the CAO QAPD Revision 1.

Page 5-6, lines 36-39: *WID QA Documents...WP 02-1 WIPP Groundwater Monitoring Quality Assurance Plan*

The title of this document since March 3, 1996 (eight months before the CCA was published) has been "Groundwater Surveillance Program Plan, Revision 3"; it is not a "Quality Assurance Plan", but five of the 25 pages (pp. 5-9) have brief sections addressing each of the 18 NQA-1 Basic Requirements.

The QAPjP for collecting meteorological data described in Appendix EMP is not listed among the WID QA documents.

5.14 Computations, Computer Codes, Models, and Methods to Demonstrate Compliance

Page 5-7, lines 9-10: *Computations and computer codes used to demonstrate compliance with 40 CFR Parts 191 and 194 are controlled as described in Section 5.3.20.*

Section 5.3.20 is a general description of computer software QA for the WIPP. It does not address computations (which are not always performed on a computer) and does not demonstrate the establishment and execution of a QA program which adheres to the requirements of the NQA standards for computer codes. It also does not describe the process for controlling the most important of computer codes for the CCA, those related to performance assessment (PA).

None of these PA codes were properly qualified (as prescribed by NQA-2 Part 2.7) for use at the time the PA calculations used in the CCA were performed (see p. 1 in Attachment 1 of the EEG July 11, 1996 Walker-to-Neill memorandum, "CAO Audit of SNL PA June 17-

21, 1996", included here as Attachment III, for a more complete discussion). Some of the important documentation for perhaps the most important computer code, BRAGFLO, had still not been completed in December, 1996--two months after the CCA was submitted, and several more months after the PA for the CCA was ran.

Page 5-7, lines 11-16: *Software supporting compliance fall into one of three categories...Table 5-1 lists the compliance software according to category.*

It is unclear why the three categories are described, as no information on the differences in QA among the various categories is supplied. Were these three categories graded differently for QA purposes?

The statement implies that all software supporting compliance is to be found in Table 5-1 (which lists only SNL's PA-related software). Other software (data acquisition, WWIS, facility design, NDA) are discussed later in this section (p. 5-9, lines 14-30), but these are not identified in Table 5-1, which is titled "Computer Software and Codes".

Page 5-7, lines 19-37: *SNL QAP 9-2, Quality Assurance Requirements for the Selection and Documentation of Parameter Values Used in WIPP Performance Assessment...The four parameter categories that are used in current compliance calculations are...1. parameters derived from experimental data...2. parameters representing inventory of the waste...3. parameters representing physical constants...4. parameters that are model configuration parameters or that are assigned based on assumed correlation of properties between similar materials.*

It is unclear why the description of the four categories of parameters is included in a section that should be discussing QA for computations, computer codes, models, and methods. Discussion of parameter categories are not a part of the requirements of either 40 CFR 191, §194, the CAG, or the NQA standards. The categories are more properly described in Appendix PAR (p. PAR.1).

Since SNL's QAP 9-2 and parameter categorization is mentioned, however, it should be pointed out that parameters of the 4th type are divided into type 4a and 4b in the version of QAP 9-2 current at the time of publication of the CCA (Revision 2, effective 09-12-96; see p. 3).

It should also be pointed that various groups of parameters are not required to comply with the complete QAP 9-2. None of the parameters entered into the PA database before 11-28-95 are required to comply with the quality-affecting portions of 9-2 according to Revision 2 (see p. 3), which was current when the CCA was published. Revision 1 did not require any of the type 4 parameters to comply with QAP 9-2, though 9-2 could be used at the discretion of the Parameters Task Leader (Rev 1, p. 3). Type 4b in the current Revision 2 are the "model configuration parameters", and are excluded from the requirements of QAP 9-2 (p. 3 of Revision 2).

...as they are not used in current compliance calculations and therefore are not subject to this procedure.

QAP 9-2 requires, among other things, that the need and intended use of a parameter be documented; that the rationale for the parameter choice (the value range) be documented; and that documentation of the parameter development be referenced or attached to the Form 464 (which is a form essential to tracing of parameters). These requirements are unique to QAP 9-2, and should be required of all parameters used. Assuming that the PA is considered a scientific investigation, the CAO QAPD Rev. 1 would seem to require use of QAP 9-2 for all but the excluded type 4b parameters under the dictates of Section 5.1.B, 5.1.C, 5.1.D, 5.1.E, and 5.1.H (other sections may also apply).

Finally, it seems useful to note that parameter data in the CCA (in Appendix PAR) is not necessarily the same values as was used in the running of the PA codes for the CCA. For example, Parameter # 3148, a concrete compressibility parameter, is listed in Appendix PAR as having a value of 1.2e-9/Pa, but is shown in the code listings for the CCA (not in the CCA; at SNL) as 2.64e-9/Pa. This difference is apparently due to Appendix PAR being taken from a later database than the one used by the PA codes for the CCA. The information and data in the CCA should be the same data that was used to demonstrate compliance.

Page 5-7, line 39, to page 5-9, line 2: *A set of screening efforts, comprised of calculations and reasoned arguments, has been identified to help define and build confidence in assumptions, data sets, and conceptual and numerical models on which the performance assessment in this application is based. Assessing the effects of features, events, and processes (FEPs) on system performance is a primary component in conceptual model development...*

No explanation as to the definition or purpose of "screening efforts" is supplied, and the terminology is rather obscure. The calculations and reasoned arguments are used to determine whether or not to include consideration of a FEP in a model, but this is not explained in the text.

The connection between screening efforts and the requirements of 40 CFR 194.22 or the NQA standards is not made clear in this section. As with the parameter categorizations, this is not a QA description but a description of an operational process.

No screening efforts other than those for FEPs are identified.

Page 5-9, lines 4-10: *FEP screening is phased. Phase I FEPs are those that could potentially affect conceptual and/or numerical models. Phase II FEPs are those that could impact parameter input to the numerical models. FEP screening analysis plans for Phase I and Phase II FEPs were developed and controlled in accordance with SNL QAP 9-1...*

Phase I and II screening were only performed separately so that SNL could meet deadlines, and under SNL QAP 9-1 could have easily been written as a single analysis plan. The necessity for describing them in the CCA chapter on QA is not apparent.

FEPs screening is an area of controversy all its own, as 40 CFR 194.32(e) requires that the CCA include documentation of the reason for excluding any identified processes or events that may affect the disposal system during the regulatory time frame. The DOE originally developed a list of nearly 1200 FEPs; the draft CCA (DOE/WIPP/CAO-2056, March 31, 1995) considered about 900 FEPs; of the 900, about 30% were addressed by Phase I and II screening plans for the CCA, and 89 of these were "screened in" to the CCA. No documentation, or screening analysis plans, were developed for the reduction of the vast majority of the nearly 1200 FEPs to the approximately 240 included in the CCA.

The FEPs which were to be addressed by Phase I and II analysis plans were not all adequately documented. The EEG asked for information on 31 of these FEPs (Neill-to-Dials letter dated July 11, 1996) and the response (McFadden-to-Dials letter dated August 2, 1996) was that screening information would be supplied only in the CCA--though the analysis plans indicate screening decision packages were to be kept for each FEP. All FEP screening decisions should have been performed according to a reviewed plan, and be adequately documented. §194.32(e) requires the CCA to include documentation of why those screened out were not included in the PA results. This was not done.

Page 5-9, lines 10-11: *Additionally the DOE and SNL have provided oversight of the FEPs screening process in the form of detailed audits and surveillances.*

Failure of the DOE and SNL detailed audits and surveillances to discover and require resolution to the FEP screening problems described above does not establish confidence in the application of the quality assurance process to FEPs.

Page 5-10, lines 20-23: *WID Documents...WP 16-117 WIPP Computer Software Quality Assurance*

This document was replaced by WP16-IT3117, Revision 0, which has the same title, on 9/26/96 (a month before publication of the CCA).

5.1.5 Expert Judgment Elicitation

This section simply states "No expert judgment activities have been identified" (p. 5-10, line 31). There have been many expert judgment activities; the question is whether or not any of these should have been performed under the formal elicitation process regulated by 40 CFR §194.26.

Some examples of expert judgment activities used in the CCA follow. Expert judgment is a part of the passive institutional control development process according to the WIPP Passive Institutional Control Peer Review Report (p. 4-3 and 4-4). Numerous parameters used in the performance assessment are justified by "investigator judgment" or "professional judgment". A November 14, 1995 RE/SPEC Inc. memorandum (RE/SPEC's Pfeifle to SNL's Diane Hurtado) outlines as part of a task plan "solicitation of expert opinion" for establishing seals parameter values, and execution of this task plan would seem to fall directly under the §194.26, Expert Judgment requirements.

5.1.6 Design of Disposal System and Actions Taken to Ensure Compliance with Design Specifications

5.1.6.1 WIPP Facility

Page 5-11, lines 6-11: *Disposal system items and processes were designed using sound engineering practices, scientific principles, and applicable industry and government standards. System design descriptions, conceptual design reports, performance requirements, and regulatory requirements are included in new designs. Designs are initiated using a classification system that ensures that the proper level of design and QA requirements is employed to meet design and testing requirements.*

The EEG and the EPA have both commented that many assertive statements in previous drafts of Chapter 5 were not substantiated. These are examples of such statements. The requirement is that the application should demonstrate that the design was established and executed under a QA program that adhered to the requirements of the NQA standards, not to merely restate those requirements. Chapter 5 contains many other such unsubstantiated statements (see, for example, most of section 3.1), so many that the EEG will desist from pointing them out--but the practice adds no substantive value to the application.

Note that the initial sentence alone covers past development of designs. NQA-1 Basic Requirement 3, Design Control, begins:

> The design shall be defined, controlled, and verified. Applicable design inputs shall be appropriately specified on a timely basis and correctly translated into design documents. Design interfaces shall be identified and controlled. Design adequacy shall be verified by persons other than those who designed the item.

The final sentences of the Chapter 5 statement is in the present tense. What QA documents show that the WIPP facility was initially designed according to the NQA standards? The documents should be properly referenced.

Page 5-11, lines 13-22: *NQA-1 Supplement 3S-1 requires that design verification be performed...Design verification was accomplished by a combination of Supplement 3S-1 methods.*

Again, this is an assertive statement which is unsupported by evidence. A reference to the document which shows that Supplement 3S-1 methods were used to verify the WIPP facility design should be referenced.

5.1.6.2 Original Repository Design

Page 5-11, lines 26-31: *After Bechtel turned systems over to the DOE, an extensive and comprehensive program of start-up testing was initiated by the DOE. The program tested systems and components against the requirements specified in design documents. This testing* *meets the requirements of Supplement 35-1 for design verification.*

The design documents and start-up testing documents should be referenced. The §194 requirement is to demonstrate that the activities described in these statements were performed, not to describe them.

Page 5-11, lines 33-38: *Brookhaven National Laboratory performed independent calculations of important design parameters...This task was documented in a report commissioned by the Office of Environmental Safety and Health (EH-30) titled, "Waste Isolation Pilot Plant Safety Evaluation Report" dated August 1989, including two subsequent addenda, the last of which closed all action items, concluding the Brookhaven effort.*

The report (referred to hereafter as the 1989 SER) is not listed in either the "References" or "Bibliography" sections at the end of the chapter, though a memorandum which apparently describes the report is. The document is dated July 27, 1989, not August. The document and addenda (Supplements) should have been properly referenced in the bibliography.

The purpose of the report was to independently document the completeness and adequacy of the Final Safety Analysis Report (FSAR) on WIPP that was current at that time (December 1988 version). The 1989 SER was only for the now-discarded "test phase" which had a 5-year lifespan rather than the 10,000 year requirements in §194, and notes that the 1989 FSAR did not include remote-handled waste (RH-TRU) in its considerations. The 1989 SER does, however, state that the review addresses the adequacy of design for the lifetime of ground structures and site characterization.

The 1989 SER also contains the following statement (p. 11-3 and 11-4):

> A Quality Assurance issue...was the failure to adequately transfer knowledge of facility design bases (Ref 13) to either DOE or the operating contractor. DOE and operating contractor staff engineer(s) were not fully knowledgeable of the details of the WIPP designs, the design calculations, specifications and drawings (as-built, ship, etc.). It is therefore unlikely that issues pertaining to the design bases, design calculations, structures, etc., and related quality control can be adequately addressed.

This is related to a concern expressed in an EH-30 Request for Additional Information, which stated that

> The FSAR states that construction management documents...are available at the WIPP Facility. Based on our efforts to collect information from the site, this is a gross misstatement of the facts. Documents are not generally available nor are they organized in any fashion which lends itself to review and/or audit...Any attempt to assess as-built conditions are clearly frustrated by such a situation. [SER Appendix B, Response to DOE/EH Request for Additional Information: Chapter 3, May 3, 1989, p. 22; the DOE's response was to simply note

that these were program management documents, not construction records]

Supplement 1 to the 1989 SER ("Supplement 1 to Safety Evaluation Report for Waste Isolation Plant" dated 01/16/90, p. II-3) notes that the WIPP committed to completing the "as-built" drawings for critical systems in the facility on a schedule provided. A memorandum from M. R. Brown, Manager of Westinghouse Engineering & Repository Technology Support, to Richard J. Figlik, WIPP Project Office, dated May 5, 1989 (see Attachment IV), illustrates the extent of the process necessary for developing the "as-built" drawings: Attachment 1 to the memorandum is a list of prioritized "as-builts" to be reconstituted, which, among other items, includes the electrical system for both the surface and underground, the environmental monitoring system, the radiation monitoring system, the underground ventilation system, the confinement facilities, the shaft hoist systems, communication systems, fire protection systems, waste handling equipment, the central monitoring system, security systems, water systems, underground testing and testing equipment, and "General Civil and Standard Systems" (which would seem to be the non-specialized items such as the site support buildings).

In short, the original QA records for design were not collected, stored, or maintained as required by NQA-1 Supplement 3S-1.7, and had to be redone. Chapter 5 should reflect the true history of QA for the facility design.

Page 5-12, line 4: *See Section 5.3.1.8 for the location of applicable QA records [for WID design].*

Section 5.3.18 (p. 5-37) contains QA records location information (there is no section 5.3.1.8).

Page 5-12, lines 24-34: *The repository sealing system design.....report [Appendix Seal] was extensively reviewed...audits and surveillances were performed on each of the primary contractors...The DOE performed oversight activities...of the SNL QA program as it relates to the SNL Sealing Systems Program...*

References to the specific audits and surveillances should have been included.

<u>5.1.7 Collection of Data and Information to Support Compliance Application(s)</u>

Page 5-14, line 17: *WID Activities: None.*

Data and information collected by WID is used throughout the CCA. Several chapters in the CCA reference the Site Environmental Reports for 1990 and 1992-1995, for example. Many of the appendices to the CCA are totally based on WID or WID subcontractor data. These include the Annual Site Environmental Report (Appendix SER); Appendix RPB, Statistical Summary of the Radiological Baseline Program for the WIPP, March, 1992; the Engineered Alternatives Cost/Benefit Study (Appendix EBS); Appendix EMP, the Environmental Monitoring Program (which wasn't mentioned as part of Environmental

Monitoring, section 5.1.2); Appendix GTMP, the geotechnical surveillance program; and Appendix GWMP, the groundwater monitoring program.

Organizations other than the DOE, SNL and WID are referenced in the CCA; for instance, Appendix HYDRO is written from US Geological Survey reports. The introduction to the Appendices (in the computerized version of the CCA) states that:

> Significant portions of the hydrological data in Chapter 2.0 are derived from this report.

Chapter 2 is Site Characterization, a major component of the CCA; and hydrological considerations are of major importance to compliance. This, too, is data and information used to support compliance, and demonstration of establishment and execution of a QA program that adheres to the NQA standards for the USGS data would seem to be a requirement of §194.22(a)(2)(vii)--though processing through the QED process allowed by §194.22(b) would seem to be a viable alternative.

5.1.8 Other Systems, Structures, Components, and Activities to the Containment of Waste in the Disposal System

Page 5-14, Lines 24-26: *At this time, the DOE has not identified any other systems, structures, components, or activities important to the waste isolation in the disposal system that require controls to be applied as described in the CAO QAPD.*

The process utilized for controlling drilling activities in the WIPP vicinity is an important activity for containment of waste with which the DOE has had problems in the past (see the "Passive Institutional Controls" section of EEG's March 14, 1997 letter to the EPA, in the WIPP docket for a pertinent example). QA oversight of this process could enhance the WIPP disposal system.

5.2 Program History

Page 5-15, Lines 1-19: *A QA program was established in late 1977 that was based on 10 CFR Part 50, Appendix B...By late 1978, DOE policy refinements had expanded the QA program to incorporate the requirements of...(ANSI)/ASME N45.2, and had extended the applicability...to all earth science activities furnishing information on the possibility of radionuclide release into the biosphere...in late 1979...The WIPP QA program was revised to meet the DOE/Albuquerque Operations Manual (Chapter WIPP), which was equivalent to the requirements of ANSI/ASME NQA-1-1979...Over the next 12 years, the WIPP QA program was revised to reflect the ...changes in upper tier QA program documents NQA-1-1979 to NQA-1-1989...*

The principle documents for the QA program(s) described, and the documents showing the changes, should be referenced. The DOE/AL Operations Manual should be included in the References/Bibliography at the end of the chapter.

The 1989 SER (FSAR review by DOE Headquarters EH-30; referenced above in comments on p. 5-11, lines 33-38) found in late 1988 (p. 11-2):

> (1) A lack of sufficient independence for the QA organization, (2) a lack of adherence to the intent of the ANSI/ASME NQA-1 Supplements, (3) a lack of an adequate design control program, (4) an inconsistent approach for the evaluation of "Important to Safety" items and services, (5) a lack of training, qualification and certification of audit, inspection, and test personnel and (6) no training and indoctrination programs.

The first attempts to address these were also woefully inadequate, indicating that basic knowledge of NQA-1 was not highly developed. The 1989 SER comments on WIPP's first response (from the 1989 SER, p. 11-3):

> The requirements of ANSI/ASME NQA-1 were quoted but no description of how they would be implemented was provided. Although there was improvement in most areas, the Quality Assurance Program still lacked: (1) identification of the responsible Quality Assurance authority and its place in the WIPP Organization Structure, (2) interface requirement between the three major participants [DOE, SNL, WID], (3) responsible authority and commitment for a Training and Indoctrination Program, (4) specific commitments for review and approval of procurement documents, (5) a requirement for receipt inspection and the option of using source inspection to accept procured items or services, (6) the specifics for waste material receipt inspection at the site, (7) responsibilities for the processing and storage of radioactive materials, (8) test procedure requirements, (9) handling and storage requirements for radioactive waste materials, (10) responsibilities for nonconformance control, and (11) qualification and certification of audit personnel.

Given that these items reflect language from many NQA-1 requirements it seems likely that the application of NQA-1 was not a significant part of the WIPP QA program before the EH-30 evaluation took place. 10 CFR 50 Appendix B, cited as the basis for the 1977 origin of WIPP QA, contains similar requirements.

A June 1, 1989 memorandum from James P. Knight, Director of the DOE's Office of Safety Appraisals, to Richard W. Starostecki, on the subject "EH Oversight of the Waste Isolation Pilot Plant Project (WIPP)" (see App. V), adds other failures in the WIPP QA program to address NQA requirements (p.2):

> A fundamental management issue also remains at this time; the adequacy of the DOE Quality Assurance (QA) program for the WIPP project. As presently structured, neither the dedicated QA staff, one person designated as the QA Manager, nor the low reporting level of the QA program meet the ANSI/ASME, NQA requirements espoused by DOE orders.

The "one person designated as the QA Manager" was the entire WIPP Project Office QA staff at the time (Westinghouse apparently had the "dedicated QA staff" mentioned). Indirect evidence also points to a lack of QA during the period up to 1989. The "as-built" design problems addressed above (see comment to page 5-11, line 33-38) were apparently never addressed by the WIPP QA organizations. Jack B. Tillman, DOE's WIPP Project Manager in 1989, testified during the June 12, 1989 hearings of the U.S. House of Representatives Environment, Energy, and Natural Resources Subcommittee of the Committee on Government Operations that:

> The as-builts have been known as a deficiency since the Corps of Engineers left the site...

(Page 171 of the printed hearings; U.S. Government Printing Office, 1990.) However, there is no evidence that responsible QA organizations pursued remediation of that deficiency in the years after the Corps of Engineers left. Any auditing activity seeking objective evidence that NQA-1 Basic Requirement 3 had been met, in virtually any area at WIPP site during this time, would have rediscovered the deficiency. Chairman Synar of the subcommittee later indicated his view of the QA program (p. 333 of the printed hearings):

> ...without an adequate quality assurance program, Mr. Tillman, I think it is very unlikely that you are going to be able to ensure that the experiments are going to be run properly, that the appropriate data is collected, and that it is applied properly.

In 1989, it appears that reviewers did not find a WIPP QA program which met the requirements of the NQA standards. Chapter 5 should reflect a more accurate history of WIPP QA.

5.3 Adequacy

"Adequacy" is later defined (p. 5-39) as the flowdown of requirements contained in upper-tier documents into implementing procedures. The subsections under this heading seem to be arranged in accordance with the Basic Requirements of NQA-1, with NQA-2 Part 2.7 and those portions of NQA-3 not already covered added at the end. This format and intent should have been made explicit in the text.

Though arranged according to the NQA standards, the subsections do not describe how all of the requirements described in the Basic Requirements and Supplements are met. The matrices mentioned on page 5-1, which link NQA requirements to the principal QA documents for the major WIPP organizations, would seem to have been more effective (and concise) in demonstrating that the WIPP QA program documents contain the requirements of the NQA standards.

In several subsections implementing documents for SNL are described as "None", even though these are requirements of the NQA standards which are applicable to SNL operations. These appear to reflect a lack of research in writing Chapter 5, rather than an absence of adequacy in the SNL QA program.

Page 5-16, lines 12-18: *From May 1993 to March 1994, DOE Headquarters...(EM-342) assessed the quality of the WIPP data acquisition process for performance assessment...The team concluded that the DOE needed to reevaluate all experimental program data used to support performance assessment.*

The EM-342 documents describing the assessment and its conclusions should be referenced.

Page 5-16, lines 20-42: *The adequacy of the current DOE QA program is ensured by passing down requirements...with the directive that applicable requirements then be passed down to lower tier organizations...Adequacy of QA program requirements are initially verified by the DOE through the review of lower-tier QA program documents prior to their implementation...Formal document review forms are used...*

QA documents that demonstrate this is being done should be referenced (the CAO QAPD in Appendix QAPD, Section 1.1.2.1 covers the majority of these requirements).

Page 5-21, Lines 1-8: *The DOE has also prepared matrices tracing the applicable NQA requirements referenced in Section 5.1 to the CAO QAPD. WID and SNL likewise are required to prepare and maintain matrices...the matrices are designated [sic] to demonstrate that the DOE, SNL, and WID QA programs are adequate and address all applicable requirements.*

Including the matrices could have been a major step in demonstrating adherence to a QA program that implements the requirements of the NQA standards, as required by 40 CFR 194.22(a)(1). These matrices would also provide substantiation for many of the assertive statements that currently lack substantiation (see comment addressing page 5-11, lines 6-11).

Page 5-21, lines 10-11: *The DOE, SNL, and WID perform assessments that include the review of implementing documents for adequacy.*

The source document(s) for this requirement should be properly referenced.

5.3.3.1 Grading

Page 5-25, line 19-21: *WID Implementing Document: WP13-QA3501 Graded Approach*

The EEG controlled copy of the WID QA procedures shows that this document was removed from the WID Quality Assurance Manual on September 27, 1996, a month before the CCA was issued. The controlled copy change notice does not indicate any replacement document. At the EPA audit of WID in February, 1997, WP13.03 Revision 0, Quality and Regulatory Assurance Department Assessment Program, effective August 26, 1996, was identified as the current implementation of the WID grading process (Section 7.3.1, "Activity Grading Process").

5.3.3.2 QA Program Documents (p. 5-25)

This section does not include SNL QA program documents. The CAG expectation (p. 18) is that DOE principle contractor top tier QA documents would be included in the CCA, not merely listed.

5.3.3.3 Qualification and Training

Page 5-26, line 2: *Personnel performing work are qualified and capable of performing their assigned tasks.*

Personnel are required to be qualified and capable--that does not mean personnel will always be so. It hasn't been in the past. for example, an SNL surveillance in November, 1995 discovered that only 2 of 30 personnel in the FEPs program had fulfilled the training requirements.

Similar overstatements, wherein a QA program requirement is described as if absolute compliance with the requirement is a certainty, are made throughout Section 5.3 subsections. These are logical fallacies for which countering examples can nearly always be found (see comment to the following section, 5.3.3.4, for another example). Such statements are usually so self-evidently overdone that most are only a minor distraction, and will not be individually pointed out.

Many of these statements also should provide a specific reference to the section(s) of WIPP QA document(s) that establishes the requirement. These will also not be individually pointed out--but assertions should always be backed by objective evidence or a path to the objective evidence.

5.3.3.4 Management Assessments

Page 5-26, lines 28-30: *Management personnel...perform assessments of the portions of the program for which they are responsible to assist in ensuring effective implementation of QA requirements.*

The CAO Manager had yet to perform an assessment of CAO at the time the CCA was published (one is scheduled for February 24-28, 1997). The NQA-1 requirement (Basic Requirement 2, last paragraph) is that management "...shall regularly assess the adequacy of the program for which they are responsible...". SNL's last WIPP Project Management Assessment (previous to the October 1996 publication of the CCA) was June 12, 1995. Corrective Action Reports on management assessments have been initiated at both CAO and SNL.

Pages 5-27 to 5-32, Sections 5.3.4 Design Control...5.3.5 Procurement Document Control...5.3.6 Instructions, Procedures and Drawings...5.3.7 Document Control...5.3.8

control of Purchased Items and Services...5.3.9 Identification and Control of Items...5.3.10 Control of Processes... No significant additional comments, though these sections do not necessarily address all the NQA-1 requirements for the area specified. For instance, section 5.3.4, Design Control, does not show how design inputs are identified, documented, reviewed, and approved, as required by NQA-1 Supplement 3S-1 2. Editorial note: page 5-30, line 31, "WP 13-QA10003" should be "WP 13-QA 1003".

5.3.11 Inspection

Page 5-32, lines 6-22: *Inspections determine acceptance or rejection of a process, product, or service. Inspection documentation for DOE participants includes the following: approved implementing procedures...DOE Implementing Documents: None SNL Implementing Documents: None*

The CAO QAPD, Rev. 1 requires that inspections be performed in accordance with approved implementing procedures (Section 2.4.1). This section implies that SNL does not have the procedure required by the CAO QAPD for conducting inspections. It further implies that there are no documents controlling SNL's inspection activities at all.

5.3.12 Test Control

Page 5-32 line 32 to Page 5-33 line 16: *...Test included as part of scientific investigations are conducted in accordance with the QA methods described in Section 5.3.21...SNL Implementing Documents: None*

Apparently all SNL tests are considered to be scientific investigations, covered by the procedures listed in Section 5.3.21. This should have been made explicit in the text, as the sense of the text in this section is that SNL has no implementing documents for control of testing.

Page 5-33 line 20: *WID Implementing Documents: WP 03-001 Preparation, Release, and Cancellation of Start-up Test Procedures*

While this is not particularly a CCA concern, the document has not been changed since August 21, 1992, and the last periodic review noted in EEG's controlled copy was August 12, 1993. Page 4-5 of the document requires control and startup QA records to be processed in accordance with WP 13-6, a procedure removed from service before September 27, 1996.

5.3.14 Handling, Storage, and Shipping

Page 5-34, lines 21-37: *Items...are handled, stored, and shipped using approved and documented methods...SNL Implementing Documents: None*

NQA-1 Supplement 13S-1.2 requires that these processes are to be "...conducted in accordance with established work and inspection instructions...or other pertinent documents or procedures specified for use in conducting the activity." This section implies that SNL has no such documents or procedures.

5.3.15 Inspection, Test, and Operating Status

Page 5-35, lines 5-7: *The specific status indicators, their use, and the authority to apply or remove them are delineated in applicable QA plans or implementing procedures...SNL Implementing Documents: None*

The implication is that SNL has no internal documents requiring compliance with NQA-1 Basic Requirement 14, Inspection, Test, and Operating Status.

5.3.16 Control of Nonconforming Items

Page 5-35, line 30 to page 36, line 13: *...When appropriate, further work on the item is halted by senior management until the appropriate actions have been taken and verified. The nonconformance control process is documented in applicable QA plans or implementing procedures...WID Implementing Document: WP13-007, Hold Tag Issuance*

In this section, neither SNL or DOE implementing documents are specified. SNL does have at least one procedure that would seem to apply to the discussion in this section (QAP 2-5, "Issuing and Lifting Stop Work Orders"); WID, too, has a "Stop Work" procedure that would also seem to apply (WP13-008).

The CAO QAPD, Rev. 1, Section 1.3.2.3.D. requires that disposition of nonconforming items, and the responsibility and authority for evaluation and disposition, be defined in QA documents (plans or procedures). The NQA-1 requirement (Supplement 15-S1.4.1) is:

> Nonconforming characteristics shall be reviewed and recommended dispositions of nonconforming items shall be proposed and approved in accordance with documented procedures.

Procedures covering the discussion of nonconforming items should have been listed.

5.3.17 Corrective Actions

Page 5-36, lines 21-23: *A significant condition adverse to quality is defined as a condition that, if not corrected, could have a serious effect on compliance with 40 CFR Parts 191 and 194.*

A statement that compliance with the EPA disposal regulations is the only defining factor for a significant condition adverse to quality is exceptionally disconcerting. This definition is simply unacceptable--A WIPP QA program utilizing such a definition would likely be unacceptable. Fortunately, the CAO QAPD, Rev 1, offers an infinitely better definition which is in use by WIPP QA (Section 1.3.2.1, p. 1-16):

> Significant conditions adverse to quality are conditions that if not corrected,

could have a serious effect on safety, operability, waste isolation, compliance, or the reliability of the QA program.

The difference between chapter 5 and the QAPD definitions of what constitutes a significant condition adverse to quality is evidence both of poor writing and inadequate review of chapter 5.

Page 5-37, lines 8-9: *Minor software problems are documented by software problem reports or other resolution mechanisms as discussed in Section 5.3.20.*

No specific mention is made of software problem reports or other resolution mechanisms in Section 5.3.20; the closest statement is (p. 5-41, lines 25-26):

For released versions, software problems are documented, evaluated, and, if appropriate, corrected.

This seems far short of the "discussion" indicated.

Page 5-37, lines 9-10: *If a software problem is determined to be a condition adverse to quality, it is documented and resolved as described in this section.*

The difference between a minor software problem, which may or may not be corrected, and a condition adverse to quality in software, for which the corrective action process must be followed, is not explained. The term "condition adverse to quality" is not defined, though "significant conditions adverse to quality" is.

5.3.18 QA Records

Page 5-37, line 36, to Page 5-38, line 6: *The records management process includes provisions for...classifying QA records as either lifetime, nonpermanent, or postclosure...*

Classification of the many unique records generated by the WIPP has yet to be accomplished, as the DOE must submit suggestions to NARA (National Archives and Records Administration) on classification of WIPP records and await NARA's guidance. The NARA positions could take some years to obtain. The provisions are in place, but many of the QA records have not been classified yet. This should have been explained in the CCA.

Page 5-38, lines 17-22: *These [QA] records are maintained by the proper organization for approved disposition. DOE QA records are retained in the document services storage facility in Carlsbad, New Mexico. SNL QA records are retained in the SNL WIPP Central Files located in Albuquerque, New Mexico, and Carlsbad. WID QA records are retained in the WID WIPP Files located in Carlsbad. Generator site QA records are retained in NQA-1 storage facilities at each site.*

Essential records are still at several subcontractor sites other than those mentioned. For instance, records related to microbial degradation of the waste were at Brookhaven National Laboratories in early February, 1997, four months after the CCA was published.

5.3.19 Audits and Surveillances

Page 5-39, lines 15-16: *The management and control of audits and surveillances are documented in QA plans or implementing procedures.*

The "implementing documents" sections for this section list procedures, but no QA plans are cited.

5.3.20 Computer Software QA

Page 5-40, lines 10-12: *Plans are prepared at the start of the software life cycle to document the software basis and objectives of the software to meet its intended use.*

This description (however it may be interpreted) falls short of describing the necessary "requirements phase" documentation specified by NQA-2 Part 2.7 sections 3.1 and 6.2. These sections require that in the requirements phase that software functionality, performance, design constraints, attributes, and external interfaces shall be specified documented, and reviewed, that the software response to anticipated classes of input data shall be defined. Section 3.1 also requires that verification and validation plans are to be written. The CAO QAPD Revision 1 (in Appendix QAPD) does contain what seems to be an adequate description of the process, and could have easily been referenced.

Page 5-40, lines 15-17: *Any software errors and failures are reported to the sponsoring organization for analysis and then forwarded to the supplier, if applicable.*

NQA-2 Part 2.7 Section 10.1 states that not only will the supplier report software errors or failures to the purchaser, but "...the purchaser shall report software errors to the supplier." No mention of determination of applicability by the purchaser is to be found in NQA-2 Part 2.7--the reporting of software errors and failures to the supplier must always be performed.

Page 5-41, lines 25-26: *For released versions, software problems are documented, evaluated, and, if appropriate, corrected.*

When would correction of software problems not be appropriate? NQA-2 Part 2.7 Section 8 does, however, have similar language:

> Corrective action by the responsible organization shall assure that: (a) problems are identified, evaluated, documented, and, if required, corrected...

Software problems that do not require correction should not be considered problems.

Page 5-41, lines 39-42: *WID Implementing Documents... WP 16-117, WIPP Computer Software*

The comment to Page 5-10, lines 20-23 was that this document was replaced by WP16-IT3117, Revision 0, same title, on 9/26/96, a month before publication of the CCA.

5.3.21 Scientific Investigations

Page 5-42 line 4-6: *Process variables affecting scientific investigations are measured and controlled as described in Section 5.3.13.*

The section referenced is "Control of Measuring and Test Equipment". Process variables other than equipment can affect scientific investigations.

Page 5-42, lines 31-32: *Scientific investigations are performed according to requirements documented in scientific notebooks or technical implementation documents or both.*

The statement reverses the order found in Section 5.2.A of the CAO QAPD Rev 1 (p. 5-2):

> Scientific investigations shall be performed in accordance with requirements documented in test plans, procedures, and scientific notebooks.

Test plans and procedures go through a series of required reviews, a comment resolution process, and approvals before promulgation; it is hard to imagine that requirements listed in scientific notebooks would undergo anywhere near the same scrutiny.

The problem of using scientific notebooks as a requirements document has cropped up at SNL in the past, when scientific investigations were in process (sometimes completed) before test plans or procedures governing the operation had finished the review and comment process. When QA assessments uncovered the deficiency the response has been that daily communications documented by entries in scientific notebooks were thought to be sufficient. If comments have yet to be resolved and approvals haven't been granted, how can the daily communications recorded in the notebooks reflect the yet-to-be-determined requirements?

If the result of the CAO QAPD statement quoted above is to allow scientific notebooks to be used as described at SNL, the CAO QAPD may have failed to fulfill Basic Requirement 2 of NQA-1. This requirement states in part that the documented quality assurance program

> ...shall provide for the planning and accomplishment of activities affecting quality under suitably controlled conditions. Controlled conditions include the use of appropriate equipment, suitable environmental conditions for accomplishing the activity, and assurance <u>that prerequisites for the given activity have been satisfied</u>. [emphasis added]

Scientific notebooks are a record of thoughts, processes, data, and results from within a scientific investigation. Planning documents establishing requirements for the investigation should be completed before the work begins. Use of scientific notebooks should not be a circumvention of the responsibility to plan, review, and authorize requirement documents for scientific investigations.

Since SNL is responsible for the bulk of scientific investigations for WIPP matters, it is worth noting that SNL QA Procedure (QAP) 20-2, Preparing, Reviewing, and Approving Scientific Notebooks, requires as the first step in the process (Section 4.1, Step 1, p. 5) that the principal investigator

> Ensure that planning is documented in an approved Test Plan according to QAP 20-1 or an approved TOP [Technical Operating Procedure]...

QAP 20-1, Preparing Reviewing, and Approving Test Plans, dictates that requirements are to be addressed in test plans (Appendix A, p.11).

Page 5-43, lines 1-2: *Uncertainty limits are assigned to the data prior to their use.*

Uncertainty limits should be derived from statistical interpretation of the data, rather than assigned (this may be simply poor word choice).

Page 5-43, line 34: *WID Implementing Documents: None*

WID performs scientific investigations (under any rational definition of the term WID's environmental monitoring program qualifies), and undoubtedly has implementing documents in the form of plans and procedures which should have been listed here.

<u>5.3.21.1 Data Quality Characteristics</u>

Page 5-43, line 38-40: *40 CFR § 194.22(c) states that to the extent practicable, data used to support compliance will be assessed according to their accuracy, precision, representativeness, completeness, and comparability.*

This is a misinterpretation of 40 CFR 194.22(c)]. The requirement is as follows:

> Any 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...[the PARCC characteristics (precision, accuracy, representativeness, completeness, and comparability)]

The requirement does not state that the data must be assessed the PARCC characteristics, only that the CCA include a description of how the assessment was performed. It is also important to note that the requirement does not limit the DOE to only considering the PARCC characteristics--the DOE could also take the opportunity to describe how other quality characteristics of the data were assessed.

Page 5-43, line 39 to page 5-44, line 2: *The DOE believes that these data quality characteristics are applicable to tasks involving the quantification through sampling and analysis of specific constituents of an environmental medium. The DOE also believes that these requirements are intended to address activities such as the determination of the presence or absence of pollutants in waste streams. Waste characterization and environmental monitoring are examples of the types of activities at the WIPP in which data quality characteristics apply. In these cases the performance measurement is the concentration of the constituent of interest.*

The DOE agrees that waste characterization and environmental monitoring activities could be assessed using the PARCC characteristics, but no description of how data from these areas were assessed is included in this section, chapter 5, or elsewhere in the CCA.

Page 5-44, lines 4-12: *In performance assessments...the performance measure is cumulative release of radionuclides to the accessible environment over the next 10,000 years. This measure is estimated using mathematical models rather than being determined by direct measurement. The performance assessment process requires the use of mathematical models for the repository, which, in general, require that numbers (here called parameters) be assigned to geologic formation and waste properties. Since many of these parameters are not amenable to direct measurement, they must be treated as uncertain variables, rather than precisely determined quantities, and characterized by probability distributions.*

There seems to be a logical jump at the beginning of this paragraph that is not warranted. The ultimate performance measurement for PA is compared with an interim performance measurement for environmental monitoring. The ultimate performance measure for environmental monitoring is determination that radionuclides have, or have not, been released, just as it is for PA; concentration values are an interim step to that measurement, just as many parameter values are for PA (the difference is, of course, that environmental monitoring results are real, while PA is a projection). Other parameter values, those "not amenable to direct measurement", should be based on data measurements to which PARCC characteristics could be applied. Finally, the PARCC characteristics do not need to be applied only to "precisely determined quantities"; for example, the completeness figure for a difficult process could be 10%, and the accuracy set to 300%. The requirement is to show how the values were assessed, not to require that narrow limits be put on the measurements.

The PARCC characteristics are a method for establishing the validity of the measurement—but that is a scientific usage, not a QA function. The §194.22(c) QA requirement is that the CCA should contain information which describes how the PARCC characteristics were assessed.

Page 5-44, lines 14-21: *Data are used to develop conceptual models for disposal system performance that are implemented as computational models in the performance assessment. Data are also used to support distributions for parameter values used in computational models. Between the point of data collection and the final computational model, uncertainty is introduced* *(for example, experimental design, extrapolation of the experimental results to spatial or temporal scales, etc.). These parameter distributions may span several orders of magnitude, and many parameters derived from data measurements need be known only within orders of magnitude of their true value. Efforts to reduce the range do not necessarily improve the model accuracy.*

The requirement is for the data, not for the computational modeling use of it. If the low-level data, based on measurements, have not been assessed for their quality, how much assurance can there be that the parameter distributions based on it are a measure of reality? An original measurement that represents a sample three orders of magnitude from the mean of the population is not much improved by establishing a three orders of magnitude range. The last sentence implies again that the PARCC characteristics are a requirement to reduce the range; they aren't. The PARCC characteristics help establish what sort of range should be used. This relates to the confidence which can be placed on the model accuracy, not the accuracy itself.

Page 5-44, lines 31-26: *Uncertainty and sensitivity analyses respectively assess the uncertainty in system performance measures and identify modeling areas and parameters in which reductions in uncertainty can increase confidence. If the uncertainty of a parameter is of significant importance to the performance of the WIPP, more data could possibly be collected to reduce uncertainty.*

This paragraph doesn't address the requirement at all. PARCC characteristics are not intended to reduce uncertainty, but to establish the quality of whatever uncertainties are used. The requirement is to ensure that an attempt has been made to address the uncertainty at the experimental data level. Uncertainty and sensitivity analyses at SNL determine the most important parameters, but it is the level of confidence in the underlying data for parameters that the application of quality characteristics is meant to establish.

Page 5-44, lines 33-38: *Instead of the above quality characteristics, other steps ensure that data are of adequate quality. Upper-tier quality requirements documents specifically define QA requirements for the collection of scientific and technical information. Section 5 of the CAO QAPD, Scientific Investigation Requirements, identifies the current requirements for data collection. For inclusion in compliance calculations, the data must be collected under an approved QA plan or otherwise be qualified.*

§194.22(a) covers the requirement for the QA program described; §194.22(c) seems clearly to be a requirement independent, and additional, to that established for the overall QA program.

Page 5-44, lines 40-43: *In summary, it is not practicable to apply data quality characteristics to most scientific investigations used to support a performance assessment in which there is uncertainty in the conceptual models and the resultant ranges of parameters. Instead, controls established by the QA program provide the necessary quality.*

The section fails to supply the required PARCC information for those scientific investigations which this summary admits are not covered by the arguments.

It is likely that some, if not most, of the underlying scientific investigations used in PA had some sort of evaluation related to quality characteristics applied to it. The PARCC characteristics in particular have been established scientific quality attributes for many years. Some of evaluations may have even been clearly prescribed and documented. Retrieval of this data would be an enormous task, and even when retrieved would not be likely to show a consistent method of application. It may be that it is not practicable to supply information in the CCA as to how the PARCC characteristics were applied to all the data used in the CCA--but the arguments used in this section of Chapter 5 are not persuasive.

The arguments presented in this section are concerned solely with the PARCC characteristics. The DOE has provided no information as to how any quality characteristics were assessed for data, at any level. It may not be practicable to always assess the PARCC characteristics, but different quality characteristics for data used in the CCA could have been defined and assessed, and information concerning these assessments could have been included in the CCA.

5.4 Implementation

This section is for the most part a well-written and accurate description of the proactive and effective WIPP QA program the EEG has observed in recent years. Many of the comments that follow are editorial in nature--but there are still significant deviations from easily discoverable facts.

5.4.1 DOE QA Program Implementation

Page 5-45, lines 26-31: *The most recent audit of DOE/CAO...concluded that the DOE/CAO QA Program was adequate and effective, but not completely implemented. They cited nonimplementation of two DOE procedures...These procedures are now fully implemented and the overall DOE QA Program is effectively implemented.*

Reference to the documentation of the acceptance by the auditors that the program is now considered to be effectively implemented should be included.

5.4.2 SNL QA Program Implementation

5.4.2.1 Data Qualification

Page 5-48 line 41 to page 5-49 line 6: *An SNL audit Internal Audit [IA] 95-03...was conducted in August 1995 to verify the adequacy and effective implementation of QA requirements...All the resulting corrective actions have been completed and verified...The audit concluded that...SNL QA controls were in place and that they were adequate and effectively implemented.*

This paragraph begins the section on data qualification, and appears as a *non sequitur* in that it doesn't seem to relate to the title. It is not until the succeeding paragraphs define what "data qualification" is that a possible clue to the applicability of the paragraph may be deduced: this audit may have established the time after which SNL's data can be said to have been developed under the NQA standards. This interpretation can only be tentatively made. The reason for including the paragraph should have been made explicit.

Page 5-49, lines 8-16: *Data can be qualified for use by one of five methods...(2) existing data collected before the implementation of a qualified QA program are qualified by showing that the data were obtained under a QA program that is equivalent to one satisfying the NQA requirements referenced in Section 5.1...*

In the Independent Review Team (IRT) process, the entire QA program did not need to be equivalent to one which satisfied the NQA requirements. Only those portions applicable to the data being qualified needed to be equivalent to NQA requirements. The difference is important, in that none of the data qualified by IRT processes was collected under a fully NQA equivalent program.

Page 5-50, lines 1-2: *...collected after August 1, 1995 when SNL QA program was qualified by the DOE (Method 1).*

The DOE document establishing the qualification should be referenced.

<u>5.4.2.2 Qualification of Existing Data</u>

Page 5-51, lines 13-14: *All data sets not qualified by IRT or collected under a qualified QA program were qualified by the peer review process.*

Only those data sets used in the CCA were qualified. About 30 data packages failed the IRT process but were not sent to peer review.

5.4.2.3 T=0 Process

Page 5-51, Lines 30-31: *The process [T=0 for subcontractors to SNL] is documented in SNL procedure QAP 20-7,* Establishing T=0 for Internal and External Experiment Activity QA Programs, *and includes the following key elements...*

Revision 0 of QAP 20-7 has an effective date of November 20, 1996, nearly a month after the CCA was published. The process used may be documented in the procedure, but an approved version of QAP 20-7 was obviously not available at the time the T=0 determinations for the subcontractors listed in Table 5-6 were made. The process of determining T=0 is a quality-affecting one, and should have been controlled by procedures or instructions as required by NQA-1, Basic Requirement 9 and Supplement 9S-1.2, and the CAO QAPD Section 2.1.A--that is, the SNL document(s) that controlled and authorized the process at the time the subcontractor T=0 determinations were made should have been cited, not QAP 20-7.

5.4.3 WID QA Program Implementation

Page 5-52, lines 36-40: *WID determines the adequacy of the implementation of QA requirements for both internal WID customers and external contractors. Internal determinations of adequacy of QA implementation are generally based on adherence to the WID QAPD requirements. The process includes a review of the contractor's QA program with regard to the applicable element of the WID QAPD, nationally recognized codes and standards, and regulations.*

The term "internal customer" is not a commonly understood term, and should have been defined.

The transition from internal QA to external contractor QA between the second and third sentences is not explicit.

Page 5-52, lines 40-43: *The WID has performed audits and surveillances to determine the dates when each of its supplier's and subcontractor's QA programs were considered adequate and effectively implemented. These dates and the basis for determination are shown in Table 5-10.*

This is the "T=0" process which was more carefully described for SNL in Section 5.4.2.3. The controlling instructions or procedures for this process required by NQA-1, Basic Requirement 9 and Supplement 9S-1.2, and the CAO QAPD Section 2.1.A, should have been cited.

<u>List of Attachments</u>

I. July 22, 1996 letter from R. H. Neill, EEG, to George Dials, DOE (Referenced on page 2 of this review.

II. Undated letter (received by the EEG on August 9, 1996), from G. Dials, DOE, to R. H. Neill, EEG (Referenced on page 2 of this review).

III. August 20, 1996 memorandum from B. Walker, EEG, to R. H. Neill, EEG (Referenced on page 16 of this review).

IV. May 5, 1989 memorandum from M. R. Brown, WID, to R. J. Figlik, WPO/DOE (Referenced on page 21 of this review).

V. June 1, 1989 memorandum from J. P. Knight, DOE, to R. W. Starostecki, DOE (Referenced on page 23 of this review).

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003
FAX (505) 828-1062

July 22, 1996

Mr. George Dials, Manager
Carlsbad Area Office
U. S. Department of Energy
P. O. Box 3090
Carlsbad, NM 88221-3090

Dear Mr. Dials:

Attached is the EEG review of Chapter 5, "Quality Assurance," from the WIPP Compliance Certification Application (CCA), published as DOE/CAO-96-2056 on May 31, 1996. Chapter 5 contains significant omissions and errors, and does not appear to meet the QA requirements listed in 40 CFR 194 or the expectations for QA as listed in the Compliance Application Guidance (CAG; EPA 402-R-95-014).

While the EPA has agreed to review the CCA a chapter at a time, the expectation was that each chapter would be a final version that would illustrate the DOE's best explanation of how the regulatory requirements for the areas covered by that chapter have been met. Chapter 5 contains many "placeholders", which are apparently to be replaced by data and analyses which have yet to be generated. Two appendices are referenced which were not included; the included Appendix RE-5 is apparently not referenced by the chapter, and is either incomplete or unnecessary. The EEG cannot provide a complete review until the additional information is added to the chapter package.

Chapter 5 also fails to meet the QA expectations listed in the CAG under the heading "§194.22 Quality Assurance" (page 18). The EPA clearly states on page 1 of the CAG that these expectations will be the criteria by which the completeness of the application will be judged, and that no further actions will be taken until the expectations are included. EEG could only verify that one of the first five expectations was included in Chapter 5. Unless it is the DOE's intention to meet the CAG QA expectations elsewhere in the CCA then Chapter 5 is also deficient in this regard.

For the most part Chapter 5 also fails to respond to the EPA comments on the Draft Compliance Certification Application (DCCA), as transmitted to your office on October 31, 1995 and January 30, 1996, and to some extent fails to address the comments published in

EEG-61, "Review of the WIPP Draft Application to Show Compliance with the EPA Transuranic Waste Disposal Standards" (March, 1996) concerning the DCCA QA Chapter. Chapter 5 contains editorial and technical difficulties which could delay the EEG and the EPA review of the complete application. A listing of some of these, as well as additional commentary on the "placeholders", CAG expectations, and other issues, can be found attached to this letter.

There is no indication in Chapter 5 that objective criteria are applied when audit teams determine the effectiveness of QA program adequacy and implementation. The process by which program effectiveness is determined should be described in Chapter 5.

Chapter 5 appears to be substantially incomplete. EEG recommends that the DOE withdraw the Chapter 5 submission, and resubmit it after (1) data to be included has been collected and analyzed, (2) the document has been rewritten to conform to CAG and other EPA expectations, and (3) full editorial and technical reviews of the contents by cognizant personnel have been performed.

Sincerely,

Robert H. Neill
Director

RHN:BAW:ss
Enclosure

**ENVIRONMENTAL EVALUATION GROUP REVIEW OF CHAPTER 5
OF WIPP COMPLIANCE APPLICATION (DOE/CAO-96-2056)**

Chapter 5 of the CCA, "Quality Assurance", published as DOE/CAO-96-2056, is an incomplete document which fails to adequately support compliance with the 40 CFR 194.22 QA requirements and the expectations for QA in the Compliance Application Guidance (CAG). This issuance of Chapter 5 appears to have been premature; material is missing, adequate technical and editorial review were apparently not performed, and there seems to have been no attempt to compare its contents against the EPA's criteria for completeness, or comments on the DCCA version of the chapter.

The following commentary is not a line-by-line review of Chapter 5, as the document is incomplete, and more general concerns should be addressed before such a review could be considered useful. Examples are randomly selected, to show the types of corrections necessary rather than a complete list of them.

Chapter 5 is an incomplete draft.

Chapter 5 as received by EEG on June 6, 1996, is a draft that would have been more appropriate in the DCCA. The document must be considered a draft, rather than a submittable document for compliance, as information has been replaced by "placeholders". The first page (5-1) has the following statement in the middle of a paragraph:

> This program of audits and surveillances assesses the adequacy and effectiveness of implementation of the individual QA programs. **[Placeholder for conclusions concerning the adequacy and effectiveness of implementation of the CAO and SNL QA programs].** (Emphasis in the original)

There are many such placeholder statements to be found in the document. Page 5-16 has one, page 5-42 has two, page 5-43 has one, 5-44 has two, 5-46 has two, 5-47 one, 5-50 three, and there may be others. The apparent reason for many of the placeholder statements is that QA activities necessary for production of a QA chapter in the CCA have not yet been completed and adequately analyzed. The placeholder quoted above, for instance, probably is due to external audits which had been scheduled, but not completed, of SNL (performed in May and June 1996) and CAO (scheduled for July 15-19, 1996) prior to the writing of Chapter 5. Other placeholders (on p. 5-46 and 5-47) are related to peer review qualification of data; these peer reviews are still in progress.

The results of these QA activities may not always support the conclusions already drawn in Chapter 5. The effectiveness of SNL's QA program was recently adjudged as "marginal" by a CAO-contracted audit, and if the DOE intends to use the results of the audit in the CCA then some sort of updating activity should be performed to show that the program is adequate.

Note that neither WID nor any of the generator sites were included in the placeholder statement quoted above. Adequacy and effectiveness of QA at these sites, too, was yet to be established at the time of publication of the document, though major audits of INEL (effective, except for ineffective ANL-West) and Rocky Flats (marginal) were performed in late 1995.

In addition to "placeholder" statements, other information to be used for compliance is yet to be obtained. For example (from p. 5-3 and 5-4, Section 5.1.1):

> The TWBIR was prepared in compliance with the CAO QAPD and was audited by CAO QA on September 5 and 6, 1996.

Since the EEG is reviewing Chapter 5 in June, 1996, it is not meaningful to take credit for an audit in September, 1996. The version of the TWBIR to be audited hasn't been published yet, either; and the version of the CAO QAPD with which it apparently is to comply was not officially transmitted to TRU-waste personnel (or EEG) until after Chapter 5 was received (distribution memo dated June 13, 1996, from CAO's QA Manager).

Until the evidence to be used in Chapter 5 has been appropriately gathered and properly analyzed, the chapter can only be considered an incomplete draft.

Chapter 5 was not adequately reviewed by the DOE.

In the above quotation, the applicable version of the CAO QAPD is not listed, nor is the version number of the TWBIR. Document version numbers are not to be found for most (if not all) documents in the chapter, which makes verification of many statements impossible.

Other editorial and technical review mistakes exist. Descriptions of the "graded approach" appear in two different places (p. 5-2 and 5-23); these provide different (though partially overlapping) sets of criteria for grading activities. Section 5.1.2 "Environmental Monitoring, Monitoring of the Performance of the Disposal System and Analysis Activities" (p. 5-6) indicates that no monitoring need take place prior to closure, in direct contrast to the §194.42(c) requirement that monitoring of critical parameters commence before waste emplacement begins. The section concerning software (5.1.4, p. 5-77 ff) considers only PA software as necessary for compliance activities, though software used in waste characterization and for site activities carried out by WID are also used for compliance with 40 CFR 194. In Section 5.3.7, Document Control (p. 5-28), WID's principal procedures for document control are not listed--and WID has been tasked with the ultimate storage of all pertinent documents to the project. Section 5.3.9 (p. 5-29) offers no objective evidence (in the form of governing procedures) to show that identification and control of items is required to be performed, though all the other sections of Section 5.3 have such references.

In Section 5.1.3,(p. 5-6), it is asserted that since the EPA had reviewed site selection and site characterization QA programs during examination of the 1989 No-Migration Variance Petition (NMVP) that the QA for site selection and characterization should be considered satisfactory. This is untenable on several grounds, not the least of which is that the NMVP is for compliance with 40 CFR 268.6, which has no requirement that QA programs must comply with the 1989 versions of NQA-1, NQA-2 Part 2.7, and NQA-3, as is found in 40 CFR 194.

Section 5.4.2 (Page 5-44) illustrates several potential deficiencies. The initial paragraph contains a statement which includes placeholders, as follows:

> A primary result of the qualification of the SNL QA audit and surveillance programs [Placeholder] the determination of which performance assessment data provided by SNL subcontractors [Placeholder] collected under an approved QA program and which data requires additional qualification.

Unfortunately, without the placeholders, the statement has effectively no useful semantic content, and cannot be analyzed in relation to the requirements of 40 CFR 194.

The next paragraph describes the change from the SNL QAPD revision P to revision R. Some mention of revision Q would prevent possible confusion.

Under the heading "Scientific Investigation" (still Section 5.4.2, p. 5-44), the statement is made that

> QAP 20-2 was added to address scientific notebooks. Previously, scientific notebooks were rarely used...

Notebooks are usually considered the basic documentation of scientific work, and the DOE may want to reconsider the phrasing of the second part of the statement.

The results of SNL Audit IA 95-03 (August, 1995) are reported in Section 5.4.2.1, Data Qualification (pp. 5-44, 45):

> The audit resulted in 14 findings in the areas of calibration, procedures, training, experimental planning, test records, and equipment and data acquisition...The audit concluded that, with the exception of the Corrective Action Requests, there was evidence that SNL QA controls were in place and that they were adequate and effectively implemented.

Given the breadth of the Corrective Action Requests(CARs), what areas were left to show adequate and effective implementation of the QA controls? In this presentation, it seems as if the program was considered adequate and effective regardless of the audit findings. Chapter 5 also lacks discussion of the process used by audit teams for determining the effectiveness of QA programs; if adequacy and implementation effectiveness statements are included in the CCA, then the process by which these statements are generated should be described.

Almost no document in Chapter 5 is properly referenced. QA documents are listed without version numbers; published government documents are listed without document numbers (p. 5-6, "Background Document..."; p. 5-14, "DOE/Albuquerque Operations Manual"), or without even a title (p. 5-11, "This task was documented in a DOE Headquarters report..."). None of these documents appear in the bibliography for the chapter, either.

Anything more than a rudimentary review by personnel familiar with the overall WIPP project and QA would have uncovered at least some of these deficiencies. In a QA chapter, the DOE has failed to adequately perform one of the basic principles of QA--review of documents. Such an omission creates an erroneous impression of the quality of QA activities that CAO has developed in the last few years.

Chapter 5 does not address CAG expectations.

While it is not a compliance requirement for DOE to fulfill the expectations in the Compliance Application Guidance (CAG EPA 402-R-95-014), the guidance was developed to assist the EPA in determining if the CCA is complete (CAG, page 1). The document goes on to state (also page 1):

> A completeness determination is a threshold determination that the application warrants further scrutiny, so that EPA, DOE, and the public do not invest major resources in a rulemaking proceeding for an incomplete document will likely (and justifiably) consider the CCA incomplete until these expectations are met.

There is no evidence in Chapter 5 that the expectations in the CAG were considered during the development of the chapter. The DOE sent out Chapter 5 with a matrix which matches the requirements of 40 CFR 194 QA requirements with the chapter, but makes no reference to the CAG expectations. There are no statements, references, or sections within Chapter 5 that echo language or structure unique to the CAG. An attempt to verify that the five expectations on page 18 of the CAG were met in Chapter 5 produced febrile results--only one of the five could be considered to be completely met. These five expectations, and the result of the EEG's verification attempt, are as follows:

1. That DOE top tier QA documents demonstrating commitment to NQA-1 (1989), NQA-2 Part 2.7 (1990), and NQA-3 (1989) be included in the CCA. Revision 1 of the CAO QAPD (if Revision 1 will be the version used for the CCA--see expectation 3) could be said to meet this requirement by itself, and evidence in Chapter 5 is that this document will be included in Appendix QAPD.

   This expectation is also the heart of the 40 CFR 194 QA requirements, and it is not likely that it was included as a CAG consideration.

2. That DOE principal contractor top tier QA documents, and a list of all top tier documents of subcontractors performing quality affecting activities as listed in §194.22(a)(2), be in the application. Appendix QAPD will apparently include the SNL and WID QAPDs, but Chapter 5 includes no listing of subcontractor documents as specified, nor the top-tier documents for generator sites, and even the TRU-QAPD may not be included in Appendix QAPD (it is not so referenced in Chapter 5).

3. That the effective dates the documents from expectation 2 were in conformance with the NQA requirements be listed in the application. No effective dates were listed for QA documents in Chapter 5; version numbers were not even given.

4. That a list of quality affecting activities and items important to demonstration of compliance be included in the CCA. No such list is in Chapter 5.

5. That the rationale used in developing the list for expectation 4 be given. No list, no explanation.

Chapter 5 is manifestly not complete according to the criteria in the CAG, nor, it seems, has DOE made an attempt to meet the completeness for QA as identified in the CAG.

The included appendix was poorly presented.

In its mailing of Chapter 5, the DOE included a separate bound document, "Appendix RE5", dated May 10, 1996. The letter of transmittal indicates that

> This appendix contains excerpts and summaries of specific references used to support CCA conclusions within the chapter. It will allow reviewers to quickly find the specific portions of referenced documents when tracing the logic of the CCA's conclusions.

EEG could find no specific references in Chapter 5 to Appendix RE5, nor was the rationale for the contents of Appendix RE5 apparent. The appendix consists of brief abstracts from the NQA standards and two NUREG position papers (1297, Peer Review, and 1298, Qualification of Existing Data). The bibliographic references for the documents duplicate the bibliography in Chapter 5. All five documents are readily available as published documents. The abstracts, when pertinent, are not so lengthy that they could not have been quoted directly in Chapter 5.

Appendix RE-5 appears to either be an unnecessary addition to the CCA, or perhaps another "placeholder" into which filler material was inadvertently placed. In any case, it is apparent that the Appendix as it exists is not a well-thought-out addition to the CCA.

Two referenced appendices were not included.

In contrast to Appendix RE-5, two other appendices are referenced in Chapter 5, but neither of these were sent with the document. "Appendix QAPD" is referenced throughout much of the chapter, and would seem to include the current QAPDs for CAO, SNL, and WID, but no complete listing of the contents is included. These documents are expectations in the CAG, along with other top-tier documents (see discussion of CAG requirements above).

"Appendix AUDIT" is said to contain results of internal audits and surveillances of the WID QA program, and lists of both internal and external audits and surveillances of the CAO, WID, and SNL (Section 5.4.4); whether generator site assessments are included as a part of "CAO" is indeterminate.

All references to Appendix AUDIT appear on the last page of Chapter 5 (p. 5-51). For such an Appendix to have real meaning, specific audits contained in it should be referenced by Chapter 5 as objective evidence that requirements have been met.

Without these appendices, the effectiveness of Chapter 5 cannot be completely assessed. Appendices QAPD and AUDIT should have been transmitted with the chapter.

Chapter 5 fails to address EEG's comments on the DCCA.

The EEG's comments on the DCCA QA chapter as published in EEG-61 (March, 1996) are also only partially addressed in Chapter 5. EEG (EEG-61 p. 5-2) suggested that the QA chapter should have addressed the requirements of 40 CFR 194.22, and Section 5.1 of Chapter 5 does address the requirements from 40 CFR 194.22(a), including the overriding requirement for conformance with the applicable NQA standards (NQA-1, NQA-2 Part 2.7, and NQA-3). However, 40 CFR 194.22(b) requires that:

> Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a)(1) [the requirement for the NQA standards] of this section have been qualified in accordance with an alternate methodology, approved by the Administrator or the Administrator's authorized representative, that employs one or more of the following methods: peer review...; corroborating data; confirmatory testing; or a quality assurance program that is equivalent in effect to...[the NQA standards].

Chapter 5 describes the processes used for data qualification by SNL (Section 5.4.2.1 and following sections, beginning on p. 5-44), but does not include information which demonstrates that the Administrator has approved of these methods.

As in the DCCA QA chapter, Chapter 5 emphasizes the QA program as it exists in 1996 over QA of the data gathering and processing activities which make up a major part of 40 CFR 194 requirements; this was another principal concern expressed in EEG-61. The CCA QA chapter should provide objective evidence that information utilized by the other sections of the CCA fulfills the quality requirements in 40 CFR 194. In places this is partially achieved; Table 5-4 contains a list of data packages qualified by the Independent Review Teams in the Qualification of Existing Data process under SNL's Quality Assurance

Procedure 20-3, but does not explain where and how these packages are used, and their importance to compliance, nor are any references or guidances provided that would allow confirmation of the table of contents.

Chapter 5 fails to adequately address EPA's comments on the DCCA.

The DOE has failed to completely address the EPA general comments on the QA chapter as provided in the enclosure from EPA's Larry Weinstock to CAO's George Dials dated October 31, 1995 (pp. 3 & 4). The EPA stated that:

> A number of assertive statements intended to describe the current status of the program are made without substantiation, including statements regarding training records, calibration records, and document and record control procedures. Objective evidence should be presented which demonstrates the successful implementation of these and other aspects of a quality assurance program for the WIPP. Examples of the evidence of implementation may include approved governing documents, implementing procedures, implementing plans and timetables, audits, surveillance, and verification reports, history of corrective actions, and the effective dates of program implementation.

Some of the governing documents, some of the procedures, and some of the effective dates of program implementation can be found in Chapter 5. However, many more assertive statements are to be found in Chapter 5 than were in the DCCA QA chapter, and objective evidence for them is not presented. A few examples follow: Section 5.1.6.2 (p. 5-11), "Original Repository Design", states that "All changes are approved by technically qualified individuals", but no evidence is supplied for the statement. Section 5.3.8 (p. 5-28), "Control of Purchased Items and Services", states that "Prospective suppliers are evaluated and selected on the basis of documented criteria", and eight bullets list other procurement controls said to be in place. However, only WID implementing documents are provided as evidences for the section, and these are for "Receipt Inspections" and "Source Inspections" (which may cover two of the eight bullets). The section does not reference the missing appendices, which might possibly include more objective evidence.

The DOE also seems to have made only a cursory attempt to address the more specific comments the EPA provided on the QA Chapter of the DCCA (transmitted as pp. 39-42 of the January 30, 1996 letter from Weinstock to Dials). For example, the first specific comment states in part, "The DCCA should have specified the roles of EM-1, EM-20, and EM-30". While Chapter 5's "Organizational Interfaces" chart (Figure 5-3, p. 5-21) shows EM-1 and EM-30, EM-20 is still not listed. The same EPA comment also implies that the organizations that conduct QA audits of contractors and waste generator sites should be listed; they aren't. Another EPA comment indicates that evidence substantiating that all workers were properly trained should be included; it wasn't.

The inclusion of the "Organization Interfaces" figure, which was not in the DCCA, implies that the EPA's comments were considered on some level. However, it also seems obvious that no line-by-line check to make sure that concerns raised by EPA comments were addressed was made. A search for a random sample of three other EPA comments--lack of objective evidence for control and maintenance of QA records, missing data quality indicators for the waste characterization program, and a need to address software reporting, correction, and implementation of requirements--shows that only the last of these is included in Chapter 5.

Chapter 5 apparently circumvents CAO's own QA program.

The weaknesses described above, in a chapter concerning QA, are apparently due to circumvention of the DOE's own QA program. CAO Management Procedure (MP) 4.4, Revision 0, dated April 19, 1996, states (Section 3.1.1) that

> Before a document is produced, the requestor should evaluate the need, end use, cost-effectiveness, intended audience, duplication of effort, regulatory and technical requirements, and any external organization's requirements or agreements related to the document.

MP 4.4 also establishes review processes, which are to be in performed in accordance with MP 4.2.

Recommendation

The DOE should consider developing not only Chapter 5 but all of the CCA under the requirements of the CAO QAPD, Revision 1. A solid quality assurance program is of little utility unless work is performed under its control.

Department of Energy
Carlsbad Area Office
P.O. Box 3090
Carlsbad, New Mexico 88221

RECEIVED
AUG 9 - 1996
ENVIRONMENTAL EVALUATION GROUP

Mr. Robert H. Neill, Director
Environmental Evaluation Group
7007 Wyoming Blvd. NE, Suite F-2
Albuquerque, N.M. 87109

Dear Mr. Neill:

We were quite surprised by your July 22, 1996 letter that expressed your concerns with Chapter 5, "Quality Assurance", of the Waste Isolation Pilot Plant (WIPP) Compliance Certification Application (CCA). Your letter implied that there are deficiencies in the Carlsbad Area Office (CAO) Quality Assurance (QA) program based upon your analysis of the Chapter 5. Contrary to this, we have shown time and again, through surveillance and audit, that the CAO QA program is effective. Let me remind you that the Carlsbad Area Office has just been audited by the Department of Energy-Headquarters (EM-30), led by an NQA-1 certified QA auditor, during which some of your staff attended, along with the Environmental Protection Agency (EPA). The report concluded that the CAO QA program was adequate and effective.

We feel that many of your comments are incorrect, exaggerated, and in some cases they reflect a basic lack of understanding of the intended requirements, expectations, and subject material. Your analysis brings to mind that we are not aware of any Environmental Evaluation Group (EEG) employee who is a certified QA auditor or has the relevant QA experience to make the judgments of a QA program as contained in your letter. Please reconsider your conclusions based upon the following:

General Comments

The following general responses are provided to express our overall disagreement and disappointment with your response. Specific responses to each of your concerns are addressed in the enclosure to this letter.

1. Your letter indicates that Chapter 5 contained significant omissions and errors. We totally disagree with this statement. Specific responses provided herein should convince you that Chapter 5 contains neither significant omissions nor significant errors.

2. With respect to the "placeholders" identified in Chapter 5: the placeholders were planned and incorporated in the May 31, 1996 revision, to flag events that had not yet occurred, but would take place at a later time. The placeholders represented assessment dates or conclusions that had not been fully completed by the May 31, 1996, Chapter 5 submittal date. The placeholders do not represent "data and analyses" as alluded to in your letter. The missing appendices referred to are not critical to the review of Chapter 5. EEG

currently has copies of the information in the appendices:

> Appendix QAPD is comprised of the CAO, SNL, and WID QAPDs. EEG has copies of these documents.
>
> Appendix SCHED is an example of a typical assessment schedule. EEG is on distribution for the quarterly issue of the CAO Assessment Schedule and the biweekly draft updates.
>
> Appendix AUDIT identifies in tabular form audits and surveillances performed by CAO, SNL, and WID, which are only indirectly related to supporting conclusions made in the Chapter. This information has also been provided to EEG in the form of the CAO Assessment Schedule.

Appendix RE-5 is a compilation of reference material from Chapter 5 and is intended to be a source of references or portions of references to make it easier for the reader. A similar appendix is included for each Chapter of the CCA.

3. Throughout your comments you refer to the "QA expectations" listed in "Section 194.22 Quality Assurance" of the Compliance Application Guidance (CAG).

   The Preamble to the CAG clearly indicates that the CAG is to be used as guidance:

   > "The CAG summarizes and explains the February 9, 1996 final rule. The United States Environmental Protection Agency (EPA) developed this guidance to assist the United States Department of Energy (DOE) with the preparation of any Compliance Certification Application (CCA) for the WIPP and, in turn, to assist in EPA's review for completeness and generally to enhance the readability and accessibility of the CCA for EPA and public scrutiny. It is EPA's intent that this guidance will facilitate the understanding that DOE and public have of the specific information that is expected to be included in a complete application for certification of compliance. Examples used for clarification in this guidance should not be considered exhaustive or definitive, since they are provided merely to facilitate DOE's understanding of the types of information EPA is expecting."

   The EPA staff clearly supports the position that the CAG is for guidance only.
   The CAG is only guidance and therefore should not be used by EEG to make an argument that Chapter 5 is deficient, nor that expectations have not been met.

4. We disagree with your statement that the May 31, 1996 revision of Chapter 5 fails to respond to EPA comments. Specific responses to the EPA Draft Compliance Certification Application (DCCA) comments were provided to EPA on January 23, 1996. In addition, the current revision of Chapter 5 has been specifically revised in format and content to address EPA DCCA comments.

5. Your comment relative to the lack of objective criteria used by audit teams "to determine the effectiveness of QA program adequacy and implementation" reflects a basic misunderstanding of QA audit processes, audit scopes, and audit terminology. Quality Assurance auditors and lead auditors are qualified and trained; lead auditors are certified. As part of their training, the three components of the audit conclusion are clearly presented. While it may appear that the process is subjective to casual observers, the process is well understood by qualified QA audit personnel. We feel that a discussion of basic auditing practices should not be included in Chapter 5.

The enclosure to this letter will further address the specific points included in your enclosure "CCA Ch. 5 (DOE/CAO-96-2056) Review."

In summary, your letter does not provide an accurate assessment of the condition, content, or quality of Chapter 5. Again, we feel that many of your comments are incorrect, exagerrated, and in some cases they reflect a basic lack of understanding of the intended requirements, expectations, and subject material.

We are, however, currently updating the placeholders and other information contained in Chapter 5 and will consider the specific comments you have made. If it is appropriate that they be addressed in Chapter 5, we will do so.

Sincerely,

George E. Dials
Manager

Enclosure

cc w/enclosure:
R. Brown, CAO
M. McFadden, CAO
J. Mewhinney, CAO
J. Maes, CAO

Enclosure

This enclosure addresses the specific comments provided by EEG in the enclosure to the "Robert H. Neill letter to George Dials, dated July 22, 1996."

Introductory Paragraphs

Chapter 5 of the CCA, "Quality Assurance", published as DOE/CAO-96-2056, is an incomplete document which fails to adequately support compliance with the 40 CFR 194.22 QA requirements and the expectations for QA in the Compliance Application Guidance (CAG). This issuance of Chapter 5 appears to have been premature; material is missing adequate technical and editorial review were apparently not performed, and there seems to have been no attempt to compare its contents against the EPA's criteria for completeness, or comments on the DCCA version of the chapter.

1. We disagree. The document <u>is complete</u> (with the inclusion of placeholders for ongoing activities).
2. We disagree. Chapter 5 <u>does</u> adequately support compliance with the 40 CFR 194.22 QA requirements.
3. We disagree. The CAG is a guidance document and does not contain requirements.
4. We disagree. The Chapter went through extensive technical and editorial revision. Over 80 pages of Document Review Records that include comments and resolutions are maintained as CAO QA records.
5. We disagree. Responses to EPA comments were provided to EPA on January 23, 1996. Additionally, the current format and content of Chapter 5 are a direct result of the EPA comments made concerning the DCCA.

"Chapter 5 is an incomplete draft."

Chapter 5 as received by EEG on June 6, 1996, is a draft that would have been more appropriate in the DCCA. The document must be considered a draft, rather than a submitable document for compliance, as information has been replaced by "placeholders". The first page (5-1) has the following statement in the middle of a paragraph:

> ***This program of audits and surveillances assesses the adequacy and effectiveness of implementation of the individual QA programs. [Placeholder for conclusions concerning the adequacy and effectiveness of implementation of the CAO and SNL QA programs]. (Emphasis in the original)***

We disagree with the comment that it "would have been more appropriate in the DCCA." The Chapter is complete (with the inclusion of the placeholders). The use of placeholders was a planned feature that permits a review of the content with the knowledge that specific information will be updated as it becomes available.

There are many such placeholder statements to be found in the document. Page 5-16 has one, page 5-42 has two, page 5-48 has one, 5-44 has two, 5-46 has two, 5-47 one, 5-50 three, and there may be others. The apparent reason for many of the placeholder statements is that QA activities necessary for production of a QA chapter in the CCA have not yet been completed and adequately analyzed. The placeholder quoted above, for instance, probably is due to external audits which had been scheduled, but not completed, of SNL (performed in May and June 1996) and CAO (scheduled for July 15-19, 1996) prior to the writing of Chapter 5. Other placeholders (on p. 5-46 and 5-47) are related to peer review qualification of data; these peer reviews are still in progress.

> We agree with your description of the reasons for the placeholders used in Chapter 5. Further classification includes: Of the 21 placeholders identified in Chapter 5, 15 are for dates to be supplied as activities occur (e.g. audit dates); three are for a description of audit conclusions (when they are reached); two are to identify the past tense; and one is a table of the packages qualified through the Peer Review process.

The results of these QA activities may not always support the conclusions already drawn in Chapter 5. The effectiveness of SNL's QA program was recently adjudged as "marginal" by a CAO-contracted audit, and if the DOE intends to use the results of the audit in the CCA then some sort of updating activity should be performed to show that the program is adequate.

> With respect to the SNL audit conducted by CAO in May 1996, the SNL QA program was determined to be "marginal." CAO had already invited EEG and EPA to attend a review of the corrective actions for those areas that contributed to the marginal conclusion. This review is currently scheduled to be held during the last week of August. This evaluation will also include a review of the status and effectiveness of critical corrective actions identified during previous assessments.

Note that neither WID nor any of the generator sites were included in the placeholder statement quoted above. Adequacy and effectiveness of QA at these sites, too, was yet to be established at the time of publication of the document, though major audits of INEL (effective, except for ineffective ANL-West) and Rocky Flats (marginal) were performed in late 1995.

> We agree, WID will be included as appropriate. However, since none of the generator sites will be certified by 10/31/96, generator sites will not be included. QA program assessment conclusions will be prepared for the generator sites at the appropriate time.

In addition to "placeholder" statements, other information to be used for compliance is yet to be obtained. For example (from p. 5-3 and 5-4, Section 5.1.1):

> ***The TWBIR was prepared in compliance with the CAO QAPD and was audited by CAO QA on September 5 and 6, 1996.***

Since the EEG is reviewing Chapter 5 in June, 1996, it is not meaningful to take credit for an audit in September, 1996. The version of the TWBIR to be audited hasn't been published yet, either; and the version of the CAO QAPD with which it apparently is to comply was not officially transmitted to TRU-waste personnel (or EEG) until after Chapter 5 was received (distribution memo dated June 13, 1996, from CAO's QA Manager).

In the above question, the applicable version of the CAO QAPD is not listed, nor is the version number of the TWBIR.

> We agree. We had also identified the typo reflecting the incorrect TWBIR audit date. The correct date was September 5 and 6, 199<u>5</u>. This has been changed. The audit was conducted in accordance with implementing procedures and CAO QAPD, Revision 0.

"Chapter 5 was not adequately reviewed by the DOE"

> We disagree with the basic premise. Chapter 5 went through a rigorous and comprehensive review process conducted in accordance with CAO MP 4.2. Over 80 pages of review comments were identified, resolved, and, where appropriate, incorporated into the document. In addition, Chapter 5 went through extensive editing for grammar, format and consistency, by professional document editors.

Document version numbers are not to be found for most (if not all) documents in the chapter, which makes verification of many statements impossible.

> We disagree with your comment relative to indicating the version, (or more correctly, the revision) of the CAO QAPD and other document referenced in the Chapter. Documents in any complex, regulated program will change over a given period of time and should always be verified for each application. Omission of the revisions for these documents is appropriate and reflects the basics of information controls.

Other editorial and technical review mistakes may be found also. Descriptions of the "graded approach" appear in two different places (p.5-2 and 5-23); these provide different (though partially overlapping) sets of criteria for grading activities. Section 5.1.2 "Environmental Monitoring, Monitoring of the Performance of the Disposal System and Analysis Activities" (p. 5-6) indicates that no monitoring need take place prior to closure, in direct contrast to the §194.42(c) requirement that monitoring of critical parameters commence before waste emplacement begins. The section concerning software (5.1.4, p. 5-77 ff) considers only PA software as necessary for compliance activities, though software used in waste characterization and for site activities carried out by WID are also used for compliance with 40 CFR 194. In Section 5.3.7, Document Control (p. 5-28), WID's principal procedures for document control are not listed—and WID has been tasked with the ultimate storage of all pertinent documents to the project. Section 4.3.9 (p. 5-29) offers no objective evidence (in the form of governing procedures) to show that identification and control of items is required to be performed, though all the other sections of Section 5.3 have such references.

1. We agree with some of the specific comments here. For example the comment relative to the grading paragraphs in the two locations. While they are included in the two separate locations for different reasons, the amount of detail in the "Applicability", Section 5.1, is not required. The description will be kept, but the details (bullets) will be deleted.

2. We agree with the comment regarding monitoring of the performance of the disposal system. Monitoring will commence prior to waste emplacement. Appendix LTM to CCA Chapter 7 will be referenced as the document describing the WID performance monitoring.

3. We agree with your comment relative to additional software that should be referenced. In our current update we have already added words to describe the application of software to data acquisition activities, WID design activities, and nondestructive assay activities.

4. We agree that one additional WID document control procedure is appropriate for reference (WID WP15-PS3103). However, we do not agree that document control and QA records are related in the manner that you indicate. The document control procedures are not intended to address "... the ultimate storage of all pertinent documents to the project." Record storage requirements are different than document control requirements. In addition we are adding one WID implementing document that addresses the identification and control of items (WP 15-PM3517).

In Section 5.1.3 (p. 5-6) the theory is advanced that since the EPA had reviewed site selection and site characterization QA programs during examination of the 1989 No-Migration Variance Petition (NMVP) that the QA for site selection and characterization should be considered satisfactory. This is untenable on several grounds, not the least of which is that the NMVP is for compliance with 40 CFR 268.6, which has no requirement that QA programs must comply with the 1989 versions of NQA-1, NQA-2 Part 2.7, and NQA-3, as is found in 40 CFR 194.

We agree with the comment on the No Migration Variance Petition (NMVP) and had already noted this. We have updated this portion of Chapter 5.

Sections 5.4.2 (Page 5-44) illustrates several potential deficiencies. The initial paragraph contains a statement which includes placeholders, as follows:

> ***A primary result of the qualification of the SNL QA audit and surveillance programs [Placeholder] the determination of which performance assessment data provided by SNL subcontractors [Placeholder] collected under an approved QA program and which data requires additional qualification.***

Unfortunately, without the placeholders, the statement has effectively no useful semantic content, and cannot be analyzed in relation to the requirements of 40 CFR 194.

> We disagree with the comment on the "semantic content" without the placeholders being included. The placeholders are intended to be replaced by the word "was" at the appropriate time to indicate that the activity has already occurred.

The next paragraph describes the change from the SNL QAPD revision P to revision R. Some mention of revision Q would prevent possible confusion.

> We disagree with the need to discuss revision "Q" of the SNL QAPD. Since EEG has observed CAO audits and surveillances of SNL starting in August of 1995, you should be aware that there is no revision "Q" of the SNL QAPD. The alpha designators "O" and "Q" are often intentionally not used due to the potential for mistaking one for the other. This was the case here.

Under the heading "Scientific Investigation" (still Section 5.4.2, p. 5-44), the statement is made that

> ***QAP 20-2 was added to address scientific notebooks. Previously, scientific notebooks were rarely used...***

Notebooks are usually considered the basic documentation of scientific work, and the DOE may want to reconsider the phrasing of the second part of the statement.

> We agree with the poorly phrased statement relative to the "previous use of scientific notebooks". This sentence will be deleted.

The results of SNL Audit IA 95-03 (August, 1995) are reported in Section 5.4.2.1, Data Qualification (pp. 5-44, 45):

> ***The audit resulted in 14 findings in the areas of calibration, procedures training, experimental planning, test records, and equipment and data acquisition...The audit concluded that, with the exception of the Corrective Action Requests, there was evidence that SNL QA controls were in place and that they were adequate and effectively implemented.***

Given the breadth of the CARs, what areas were left show adequate and effective implementation of the QA controls? In this presentation, it seems as if the program was considered adequate and effective regardless of the audit findings.

> We disagree with your overall conclusion regarding the SNL internal audit (IA-95-03). The executive summary indicated:

> "Within the scope of this audit it was determined that, with the exception of the identified CARs, there was evidence that SNL QA controls were in place and that they were adequately and effectively being implemented for those experimental programs addressed in Phases 1, 2, and 3."

There were 14 criteria evaluated over 11 experimental programs. The 14 CARs were distributed over the 11 experimental programs and were not concentrated in one particular area or in one particular program. Thus, neither the criteria nor the programs were compromised to the extent that the audit team would conclude that implementation was not effective.

Chapter 5 also lacks discussion of the process used by audit teams for determining the effectiveness of QA programs; if adequacy and implementation effectiveness statements are included in the CCA, then the process by which these statements are generated should be described.

We disagree with the need to include a discussion of basic auditing conclusions (adequacy, implementation and effectiveness). The CCA is not intended to be a primer on "how to audit".

Almost no document in Chapter 5 is properly referenced. QA documents are listed without version numbers; published government documents are listed without document numbers (p. 5-6, "Background Document..."; p. 5-14, "DOE/Albuquerque Operations Manual"), or without even a title (p. 5-11, "This task was documented in a DOE Headquarters report..."). None of these documents appear in the bibliography for the chapter, either.

1. We disagree with the need to include document versions, revisions, or other designators in the CCA. As previously indicated, Chapter 5 describes the QA program that is directed to the control of important WIPP activities. This program will constantly be changing as requirements, expectations, or the need for improvements arise.

2. We agree that the DOE Headquarters report should be identified. We had already researched the document title and date and have included it in the Chapter.

Anything more than a rudimentary review by personnel familiar with the overall WIPP project and QA would have uncovered at least some of these deficiencies. In a QA chapter, the DOE has failed to adequately perform one of the basic principles of QA--review of documents. Such an omission creates an erroneous impression of the quality of QA activities that CAO has developed in the last few years.

1. We disagree with the comment concerning "A rudimentary review by personnel familiar with the overall WIPP project and QA would have uncovered at least some of these deficiencies." As previously indicated Chapter 5 received extensive QA and editorial reviews. Likewise, we disagree with the use of the word "deficiencies".

Most of the EEG comments relate to areas that have been planned to be upgraded during the current review or comments relative to alternate ways to approach the Chapter.

2. We disagree with the statement that "DOE has failed to adequately perform one of the basic principles of QA -- review of documents. Such an omission creates an erroneous impression of the quality of QA activities that CAO has developed in the last few years." Review is not one of basic principles of QA, rather it is an activity that supports QA principles. The type of generalization indicated in this comment without any idea of the process that was used, is unprofessional and unnecessary.

"Chapter 5 does not address CAG expectations."

While it is not a compliance requirement for DOE to fulfill the expectations in the CAG, the guidance was developed to assist the EPA in determining if the CCA is complete (CAG, page 1). The document goes on to state (also page 1):

> ***A completeness determination is a threshold determination that the application warrants further scrutiny, so the EPA, DOE, and the public do not invest major resources in a rulemaking proceeding for an incomplete document will likely (and justifiably) consider the CCA incomplete until these expectations are met.***

There is no evidence in Chapter 5 that the expectations in the CAG were considered during the development of the chapter. The DOE sent out Chapter 5 with a matrix which matches the requirements of 40 CFR 194 QA requirements with the chapter, but makes no reference to the CAG expectations. There are no statements, references, or sections within Chapter 5 that echo language or structure unique to the CAG. An attempt to verify that the five expectations on page 18 of the CAG were met in Chapter 5 produced febrile results--only one of the five could be considered to be completely met. These five expectations, and the result of the EEG's verification attempt, are as follows:

> We agree that Chapter 5 is not complete with respect to the CAG, however, we disagree with your conclusion that it must be. The Preamble of the CAG, clearly indicates that the CAG is to be used as guidance. The EPA staff clearly supports the position that the CAG is for guidance only.
>
> The CAG is only guidance and, therefore, should not be used by EEG to make an argument that Chapter 5 is deficient nor that expectations have not been met.

"The included appendix was poorly presented."

In its mailing of Chapter 5, the DOE included a separate bound document, "Appendix RES", dated May 10, 1996. The letter of transmittal indicates that

> *This appendix contains excerpts and summaries of specific references used to support CCA conclusions within the chapter. It will allow reviewers to quickly find the specific portions of referenced documents when tracing the logic of the CCA's conclusions.*

EEG could find no specific references in Chapter 5 to Appendix RE5, nor was the rationale for the contents of Appendix RE5 apparent. The appendix consists of brief abstracts from the NQA standards and two NUREG position papers (1297, Peer Review, and 1298, Qualification of Existing Data). The bibliographic references for the documents duplicate the bibliography in Chapter 5. All five documents are readily available as published documents. The abstracts, when pertinent, are not so lengthy that they could not have been quoted directly in Chapter 5.

Appendix RE5 appears to either be an unnecessary addition to the CCA, or perhaps another "placeholder" into which filler material was inadvertently placed. In any case, it is apparent that the Appendix as it exists is not a well-though-out addition to the CCA.

> We disagree. The Appendix RE5 is a compilation of reference material from Chapter 5. Appendix RE5 is intended to be a source of references or portions of references in context to make it easier for the reader. A similar Appendix is included at the end of each CCA Chapter.

"Two referenced appendices were not included."

In contrast to Appendix RE5, two other appendices are referenced in Chapter 5, but neither of these were sent with the document. "Appendix QAPD" is referenced throughout much of the chapter, and would seem to include the current QAPDs for CAO, SNL, and WID, but no complete listing of the contents is included. These documents are expectations in the CAG, along with other top-tier documents (see discussion of CAG requirements above).

"Appendix AUDIT" is said to contain results of internal audits and surveillances of the WID QA program, and lists of both internal and external audits and surveillances of the CAO, WID, and SNL (Section 5.4.4); whether generator site assessments are included as a part of "CAO" is indeterminate.

Without these appendices, the effectiveness of Chapter 5 cannot be completely assessed. Appendices QAPD and AUDIT should have been transmitted with the Chapter.

> The missing appendices are not critical to the review of the chapter, but are now included.
>
> Appendix QAPD is comprised of the CAO, SNL, and WID QAPDs. EEG has copies of all three documents.
>
> Appendix SCHEDULE is an example of a typical assessment schedule. EEG is on distribution for the quarterly issue of the CAO Assessment Schedule and the weekly draft updates.

Appendix AUDIT is a list of audit and surveillances that were conducted by CAO, SNL, and WID, which are only indirectly related to supporting the conclusions made in this Chapter. EEG is on distribution for the quarterly issue of the CAO Assessment Schedule and the weekly draft updates.

Since none of the generator sites will be certified by 10/31/96, generator site assessments are not included as a part of Appendix AUDIT.

"Chapter 5 fails to address EEG's comments on the DCCA."

The EEG's comments on the DCCA QA chapter as published in EEG-61 (March, 1996) are also only partially addressed in Chapter 5. EEG (EEG-61 p. 5-2) suggested that the QA chapter should have addressed the requirements of 40 CFR 194.22, and Section 5.1 of Chapter 5 does address the requirements from 40 CFR 194.22(a), including the overriding requirement for conformance with the applicable NQA standards (NQA-1, NQA-2, Part 2.7, and NQA-3). However, 40 CFR 194.22(b) requires that:

> ***"Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a)(1) [the requirement for the NQA standards] of this section have been qualified in accordance with an alternate methodology, approved by the Administrator or the Administrator's authorized representative, that employs one or more of the following methods; peer review...; corroborating data; confirmatory testing; or a quality assurance program that is equivalent in effect to...[the NQA standards]."***

We disagree that the purpose of Chapter 5 includes addressing EEG comments. EEG comments were addressed and included in the January document that addressed <u>all</u> comments on the DCCA. You were provided a copy of this document by letter dated January 23, 1996.

Chapter 5 describes the processes used for data qualification by SNL (Section 5.4.2.1 and following Sections, beginning on p. 5-44), but does not include information which demonstrates that the Administrator has approved of these methods.

We disagree with your interpretation of when the Administrator has to approve methods for qualifying data and information collected prior to the implementation of the quality assurance program. It is our opinion that the EPA Administrator's authority in this area begins with the submittal of the CCA.

Table 5-4 contains a list of data packages qualified by the Independent Review Teams in the Qualification of Existing Data process under SNL's Quality Assurance Procedure 20-3, but does not explain where an dhow these packages are used, and their importance to compliance, nor are any references or guidance provided that would allow confirmation of the Table contents.

We disagree with the need to explain where and how QED packages are used and their importance to compliance in Chapter 5. This technical information is not appropriate to this chapter and is discussed in other CCA Chapters.

"Chapter 5 fails to adequately address EPA's comments on the DCCA."

Chapter 5 fails to adequately address EPA's comments on the DCCA.
The DOE has failed to completely address the EPA general comments on the QA chapter as provided in the enclosure from EPA's Larry Weinstock to CAO's George Dials dated October 31, 1995 (pp. 3&4). The EPA stated that:

> ***"A number of assertive statements intended to describe the current status of the program are made without substantiation, including statements regarding training records, calibration records, and document and record control procedures. Objective evidence should be presented which demonstrates the successful implementation of these and other aspects of a quality assurance program for the WIPP. Examples of the evidence of implementation may include approved governing documents, implementing procedures, implementing plans and timetables, audits, surveillance, and verification reports, history of corrective actions, and the effective dates of program implementation."***

Some of the governing documents, some of the procedures, and some of the effective dates of program implementation can be found in Chapter 5. However, many more assertive statements are to be found in Chapter 5 than were in the DCCA QA chapter, and objective evidence for them is not presented.

We disagree with your statement that the May 31, 1996 revision of Chapter 5 fails to respond to EPA comments. Specific responses to the EPA DCCA comments were provided to EPA on January 23, 1996. In addition, the current revision of Chapter 5 has been specifically revised in format and content to address EPA DCCA comments.

A couple of examples: Section 5.1.6.2 (p. 5-11), "Original Repository Design", states that "All changes are approved by technically qualified individuals", but no evidence is supplied for the statement. Section 5.3.8 (p. 5-28), "control of Purchased Items and Services", states that "Prospective suppliers are evaluated and selected on the basis of documented criteria", and eight bullets list other procurement controls said to be in place. However, only WID implementing documents are provided as evidences for the section, and these are for "Receipt Inspections" and "Source Inspections" (which may cover two of the eight bullets). This section does not reference the missing appendices, which might possibly include more objective evidence.

We disagree. Because WID is responsible for design, only WID implementing documents are appropriately provided Sections 5.3.8.

We disagree that the comment concerning qualifications and training of workers is not addressed. Section 5.1.6.2 (p 5-11) does state that changes are approved by "technically qualified individuals." Chapter 5 describes the CAO QA program that is used to train and qualify personnel. These records are subject to the audit process. Individual qualification and training records are maintained as QA records. We do not believe that the thousands of records for all WIPP personnel performing quality affecting activities are appropriate to be included in the CCA. These records are subject to the audit process.

The DOE also seems to have made only a cursory attempt to address the more specific comments the EPA provided on the QA Chapter of the DCCA (transmitted as pp. 39-42 of the January 30, 1996 letter from Weinstock to Dials). For example, the first specific comments states in part, "The DCCA should have specified the roles of EM-1, EM-20, and EM-30". While Chapter 5's "Organizational Interfaces" chart (Figure 5-3, p. 5-21) shows EM-1 and EM-30, EM-20 is still not listed. The same EPA comment also implies that the organizations that conduct QA audits of contractors and waste generator sites should be listed; they aren't. Another EPA comment indicates that evidence substantiating that all workers were properly trained should be included; it wasn't.

We disagree. Chapter 5's "Organizational Interfaces" chart is correct in not identifying EM-20. The EM-20 responsibility for QA oversight of WIPP has been re-assigned to EM-30. EM-30 recently performed an independent assessment of the CAO QA Program.

The inclusion of the "Organization Interfaces" figure, which was not in the DCCA, implies that the EPA's comments were considered on some level. however, it also seems obvious that no line-by-line check to make sure that concerns raised by EPA comments were addressed was made. A search for a random sample of three other EPA comments--lack of objective evidence for control and maintenance of QA records, missing data quality indicators for the waste characterization program, and a need to address software reporting, correction, and implementation of requirements--shows that only the last of these is included in Chapter 5.

We disagree that the EPA comments have not been addressed as identified by the random sample of three EPA comments - lack of objective evidence for control and maintenance of QA records, missing data quality indicators, and a need to address software reporting, correction, and implementation of requirements. The comments are addressed within the discussion of the appropriate implementing procedures and overall controls established by the QA Program. We do not consider it necessary to supply more detail in Chapter 5.

"Chapter 5 apparently circumvents CAO's own QA program."

The weaknesses described above, in a chapter concerning QA, are apparently due to circumvention of the DOE's own QA program. CAO Management Procedure (MP) 4.4, Revision 0, dated April 19, 1996, states (Section 3.1.1) that

> ***Before a document is produced, the requestor should evaluate the need, end use, cost-effectiveness, intended audience, duplication of effort, regulatory and technical requirements, and any external organizations's requirements or agreements related to the document.***

MP 4.4 also establishes review processes, which are to be in performed in accordance with MP 4.2.

1. We disagree with this topic in its entirety. The review process was conducted in accordance with MP 4.2. Results of the reviews, for this revision of CCA Chapter 5, including comment resolution documentation, were completed and are maintained as QA records.

2. We disagree that the CAO QA Program was circumvented in any respect and believe this EEG determination was based on a lack of facts and a lack of understanding of the CAO Quality Assurance Program.

Attachment III to EEG Review of CCA, Chapter 5

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY · AFFIRMATIVE ACTION EMPLOYER

505 NORTH MAIN STREET
POST OFFICE BOX 3149
CARLSBAD, NEW MEXICO 88221-3149
(505) 885-9675
FAX (505) 887-0243

MEMORANDUM

DATE: August 20, 1996

TO: Robert H. Neill, Director

FROM: Ben Walker, QA Specialist

SUBJECT: CAO Audit of SNL PA June 17-21, 1996

Tom Clemo and I observed the CAO audit of SNL's PA program during the week of June 17-21, 1996. Seven auditors were involved; other observers were Marc Italiano and George Basabilvaso from CAO, and Patrick Kelley, James Channell, David Back, and William Sublette for the EPA.

The audit team judged the PA program implementation of QA to be "marginal", and the software development and qualification was judged "marginally effective". Five draft Corrective Action Reports (CARs) were generated, and eight draft observations. Attachment 2 is a listing of these draft CARs and observations, and other material presented by the lead auditor at the closeout meeting.

Two items would seem to be of particular concern to QA for the PA effort: software codes were still not qualified, and some parameter values used by PA codes had been entered into the parameter database without formal processing. The software codes had incomplete baseline documentation but were nevertheless being utilized in Compliance Certification Application (CCA) calculations. The SNL QA Manager had agreed to this usage. The parameter value changes were a different sort of problem, in that the well-established parameters data entry formalism at SNL had been circumvented for the entry of some 25 parameter changes. These two events do not increase confidence in SNL's commitment to established quality for PA calculations.

A more complete description of these findings, and other events that took place during the audit, can be found in Appendix 1. The audit also found several laudatory practices at SNL; these include ease of retrieval of documents from the Sandia WIPP Central Files (SWCF), extensive error checking of inputs, software test scripting, and documentation and archiving of software production runs. As always, SNL personnel were for the most part easily accessible and very helpful.

The auditors were well prepared, and those I observed stayed on task. Their knowledge and experience with SNL's QA efforts were readily apparent; and as is usual with CAO's auditors, they were persistent and thorough. This was a conscientious audit.

BAW:TC:ss
Enclosures

ATTACHMENT 1 to SNL PA Audit

Attachment 1 of the memorandum on the SNL QA audit (Walker to Neill, May 24, 1996) stated that:

> There still seems to be a sense at SNL that QA is secondary to scientific pursuit rather than an integral, and, for this project, essential part of it, and this attitude may have its effects even on QA personnel and their activities.

This hypothesis receives additional support from the sections that follow.

Software Qualification

Evidence of considerable effort to get the PA codes into QA conformance has been demonstrated in other software assessments in the recent past, and the documentation viewed in this audit was of good quality. However, SNL has decided to run calculations for the CCA using codes that are not yet in accordance with the dictates of NQA-2 Part 2.7, the 40 CFR 194 standard cited for software QA.

None of the PA codes were found to be fully qualified during the audit. Memoranda dated May 23, 1996 from the PA Manager in charge of software to the SNL QA Manager list the "current QA status" of each of the codes, all of whom contained incomplete items, and then request permission from the QA Manager to proceed with the CCA calculations. The QA Manager signed approval of the requests, without so much as initiating a CAR or requiring a schedule for completions.

A copy of the memorandum for NUTS is attached (Attachment 3); the distribution list shows that no copies were provided to the CAO. Nearly all aspects of the QA process are said to be "in progress"--i.e., none were completed. This includes the Requirements Document (RD) and the Verification and Validation Plan (VVP), which make up the first step in the NQA-2 Part 2.7 life cycle for software (§ 3.1, Requirements Phase), and define the requirements for the design of the testing phase and test cases. The memorandum later states that "Test cases #1 through #9 have been run" (though the requirements are still in draft) and that "...the testing is far along...."

The memorandum for CUTTING_S listed similar deficiencies (for all developmental parts of the software life cycle) in similar language. The other memoranda were probably similarly organized, though completion of parts of the life cycle may have occurred. NQA-2 Part 2.7 § 3 states:

> Software development shall proceed in a traceable, planned, and orderly manner...Software development may be performed in an interactive or sequential manner.

While "interactive" might be interpreted to indicate that test results can be used to change code requirements in an iterative fashion, it does not imply that all parts of the life cycle can be developed in parallel. Operational use of the software is the penultimate (6th) step in the software life cycle (followed only by the "retirement phase"), and NQA-2 Part 2.7 clearly states that for the "Operations and Maintenance Phase" (§ 3.6):

> Prior to this phase the software has been approved for operational use.

The memoranda also contain the statement that "The remaining testing and QA documentation will be completed expeditiously", and (for NUTS) that "If this testing uncovers any problems with NUTS then the impact on the CCA calculations would be assessed at that time". It seems likely that the purpose of the memoranda is to remove the pressure to complete QA work expeditiously; and the cost and effort to completely trace errors through a submitted CCA could be extensive.

The process to be followed as described in these memoranda are clearly at odds with the 40 CFR 194 requirements concerning software.

Parameter Entry Control

SNL-WIPP Form 464, WIPP Parameter Entry Form, is required for entry of any parameter values or changes in these values to the database for use by PA. Form 464s are initiated by the Parameter Task Leader, who enters information on the parameter, the change to be made, and justification for the change, attains signatures of the change requestor and an approval signature (others are sometimes required), then submits the Form 464 and supporting information to the Database Administrator as a Parameters Records Package (PRP). Data entry personnel are trained to use the Form 464s for input; the data entry person's signature is added to the 464, as is the signature of the person who checks the entry. The PRP, including the Form 464, is then filed in the Sandia Wipp Central Files (SWCF).

At the February 16, 1996, closeout of a CAO surveillance of parameters the lead auditor complimented SNL on the rigor with which use of Form 464s was enforced for database entry.

An auditor uncovered three or four parameters in the database for which no Form 464s could be found. In pursuit of this problem, the auditors were eventually shown a list of 25 parameters titled, "CHANGES NOT COVERED BY 464's". According to notes took while viewing this list, the first change entered was on February

16, 1996 (date of the closeout compliment mentioned above). That these entries had circumvented the established requirements was uncovered about a week later by a PI (while researching a parameter request from EEG). The compiling of the list began at that time.

It is one sort of error to fail to follow practices that have yet to be firmly established; it's another to fail in follow those that are established. During the audit we suggested that the audit team should find out the details of how these entries were made. We were informed that SNL would have to perform that activity and report it to CAO as part of the CAR resolution. It is hoped that the entries are the result of a preoccupied PI submitting changes directly to an improperly trained data entry person, but the problem is likely more serious.

In defense of SNL, this has all the appearances of being a single lapse in which all 25 parameters were changed in a matter of days, and SNL personnel were attempting to establish proper documentation. On the other hand, no internal CARs were generated by SNL's discovery of the problem.

Procedure Problems I: Data qualified by audit

During the audit, I had reason to read the versions of SNL QAPs 9-1 and 9-2 used by the auditors, and discovered lapses in each.

QAP 9-1 version 1 contained the statement (Section 4.3, Step 2):

> When data sets are used to support the analysis, document the source of the data and whether the data have been qualified through collection under an approved SNL QA program, the application of QAP 20-3, *or by SNL WIPP audit* (emphasis added).

Audits do not qualify data. When I questioned this statement it was explained to me that the phrase was more a slang term, and what was meant was that the program under which the data was developed had been audited by SNL to confirm that the program conformed to SNL's QA standards.

I was told SNL was in the process of revising the procedure, and indeed they were. EEG now has a copy of Revision 2 of the procedure, which became effective April 11, 1996, (a copy was received at EEG on April 18, 1996) and the statement quoted above has been removed. I remain confused, however. The audit was two full months after the effective date of the revision; why were auditors using the older one? And, why wasn't I simply shown that the newer version did not contain the item in question?

Analysis Plan AP-018, version 00, "Groundwater Modeling Analysis Plan for the Generation of Transmissivity Fields for the Culebra

Flow and Transport Calculations", dated May 2, 1996, Section 3.1, contained a similar statement:

> Only data that has been qualified through collection under an approved SNL QA program, through application of QAP 20-3, or *by SNL WIPP* audit will be used for this analysis [emphasis added].

I suspect this document was written with QAP 9-1 in hand; other analysis plans may have similar statements. This is an example of why the writing and reviewing of QA documentation is so important.

Procedures Problems II: Parameter "Category" Definitions

QAP 9-2, "Quality Assurance Requirements for the Selection and Documentation of Parameter Values Used in WIPP Performance Assessment" presented a more serious problem. The definition of parameter categories indicates that adequate control over parameters may not be adequately performed. Section 2.0 of the procedure offers a list of five categories, and states that Category 1, 2, and 3 parameters are subject to the requirements of the procedure, but 4 and 5 are not. The QAP 9-2 Revision 1 Category table:

Category	Description
5	Parameters not used in current compliance calculations;
4	Parameters that are model configuration parameters or that are assigned based on an assumed correlation of properties between similar materials;
3	Parameters representing physical constants...
2	Parameters representing the inventory of the waste to be emplaced at WIPP...
1	Parameters that do not fall into Categories 2 through 5, but are necessary to WIPP PA calculations.

The audit team failed to see why Category 4 parameters were deemed to be excludable from the QA requirements, and that the process for categorization of parameters was not adequate; a draft observation to that effect was made (draft Observation No. 3; in Attachment 2, p. 5).

I thought it should have been a CAR (and inappropriately said so at an audit team caucus). The table is unnecessarily confusing for the purpose of the procedure (establishing QA for parameters). The procedure should have been written to require documentation for all parameters used in PA considerations, and should also require a documented rationale for parameters that are dropped from use in PA.

EEG's controlled copy version of SNL QAP 9-2 still shows Revision 1 as the current process to follow (August 9, 1996). The draft observation apparently had no effect on SNL, and parameters can still be included in PA calculations without necessarily being adequately documented.

Dating on Documents

Many kinds of SNL documents have inconsistencies in the dates listed in them. I have noticed several during previous audits and surveillances, but since the dates are always reasonably close I've not documented them.

Most pernicious are reviews or approvals of documents with dates that post-dated the issuance of the documents. For example, six Form 464s were found which were started on April 23, 1996, and entered into the database on April 22, 1996. The approvals for the change were all dated April 23, 1996.

Analysis plans I viewed had similar inconsistencies. "Analysis Plan for ORIGEN2 Inventory Calculations for First Phase Determination of the Initial Radionuclide Inventory for Performance Assessment Analysis Supporting the Compliance Certification Application", dated April 4, 1996, had all its signatures on or after April 9, 1996. "Analysis Plan for the Salado Flow Calculations (Task 1) of the Performance Assessment Analyses Supporting the Compliance Certification Application" was effective March 8, 1996, yet the author and reviewer signatures were dated March 12, 1996.

An internal SNL surveillance (96-08) of software was conducted on April 9-11, 1996. The surveillance report contains the following statement:

> One item of concern was the inconsistency of document dates. As this has been identified by CAO CAR 96-036, the inconsistencies will be listed in this report for correction without an additional CAR being issued.

The report has nine pages of documentation of violations which fall under CAO CARs for document dates and comment resolution. The report itself has an inconsistent date: the date on the memorandum transmitting it is April 3, 1996, 6 days before the surveillance took place.

Resolution of Previous CARs

A part of the scope of this audit was to verify the effectiveness of corrective actions for previous CAO CARs. None of the corrective actions were found by the auditors to be effectively implemented during this audit. Some, but not all, of the "observations" (a category for findings that could potentially generate CARs in the future if not corrected) for which CAO required responses were found to be adequately addressed.

Project Technical Baseline Updating

The FEPs plan suggested that the Project Technical Baseline (PTB) be updated. Discussions with SNL employees indicated that although significant changes in nearly all portions of the baseline have been instituted, SPM-2 (established in 1994) was still the PTB of record. "The CCA itself will be the new baseline" one employee stated, and suggested that the FEPs plan would be changed rather than establishing a pre-CCA update of the baseline.

U.S. Congress H.R. Hrg. 101-6/12

Attachment IV to EEG Review of CCA, Chapter 5

REVIEW OF THE STATUS OF THE WASTE ISOLATION PILOT PLANT PROJECT

pg. 163

HEARING

BEFORE THE

ENVIRONMENT, ENERGY, AND NATURAL RESOURCES SUBCOMMITTEE

OF THE

COMMITTEE ON GOVERNMENT OPERATIONS HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

JUNE 12, 1989

Printed for the use of the Committee on Government Operations

U.S. GOVERNMENT PRINTING OFFICE
21-132 ⸺ WASHINGTON : 1990

Westinghouse Electric Corporation

Government Operations

Waste Isolation Division

Box 2078
Carlsbad NM 88221

May 5, 1989
WD:89:00514

Mr. Richard J. Figlik, Manager
Management Support Staff
U. S. Department of Energy
WIPP Project Office
P. O. Box 3090
Carlsbad, NM 88221-3090

DRAFT PLAN FOR AS-BUILTS

Dear Mr. Figlik:

Four different completion times have been looked at for completion of as-builts. The completion times looked at are 15 months, 12 months, 9 months and less than 9 months. The data provided in the previous correspondence, HA:89:4057 dated 4/26/89, was used as a basis for the plan development, the system breakout, and the system priority Currently, there are no funds within Westinghouse or people to support an as-built program. Past progress in this area has been made with people or funds diverted from other work. To get a quality product, a dedicated effort is needed. In order to obtain the necessary field data, there will be plant power outages and other impacts. Cables will have to be traced or rung out. It was assumed that the work would be conducted on any shift that the systems were available. Hourly rates and per diem costs are actual costs from PEAK. Where possible to prevent wasted time, activities would be worked in parallel. Due to problems scheduling outages, each team could be working on 5 or 6 systems at a time.

This document does not identify resources to correct any deficiencies discovered during the as-built program.

Sincerely,

M. R. Brown, Manager
Engineering & Repository
Technology Support

MRB/dc:3

HA:89:4064

Attachments (1): System Priority List
(2): Plan for Less than 9 Months
(3): Plan for 9 Months
(4): Plan for 12 Months
(5): Plan for 15 Months

U.S. Congress H.R. Hrg. 101-6/12

Attachment V of EEG Review of CCA, Chapter 5

REVIEW OF THE STATUS OF THE WASTE ISOLATION PILOT PLANT PROJECT

pgs. 330-332

HEARING

BEFORE THE

ENVIRONMENT, ENERGY, AND NATURAL RESOURCES SUBCOMMITTEE

OF THE

COMMITTEE ON GOVERNMENT OPERATIONS HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

JUNE 12, 1989

Printed for the use of the Committee on Government Operations

U.S. GOVERNMENT PRINTING OFFICE

United States Government | Department of Energy

memorandum

DATE: JUN 1 [illegible]

REPLY TO ATTN OF: EH-331

SUBJECT: EH Oversight of the Waste Isolation Pilot Project (WIPP)

TO: Richard W. Starostecki, EH-30

This Office has completed two major efforts related to the oversight of WIPP. On April 28, 1989, we completed a one-week, onsite review of the WIPP Final Safety Analysis Report (FSAR). On May 15, 1989, we completed a Readiness Review Inspection (RRI). The EH staff trip report summarizing the FSAR review, dated May 4, 1989, and the RRI report are attached to this memorandum. Your approval of the RRI report by signature on the cover page is requested.

During the FSAR review a team of EH staff and consultants interacted with DOE WIPP Project Office (DOE/WPO), Westinghouse, and Bechtel representatives to close out requests for information flowing from our review of the FSAR and supporting documents. This effort also included resolution of questions that arose from independent calculations performed for EH by Brookhaven National Laboratory (BNL).

Most of the information required to close EH concerns related to the FSAR was developed during the onsite FSAR review. The task was inhibited by almost total reliance on a single Bechtel representative to provide information related to the design or technical basis for selection of the structures, systems, and components that comprise the WIPP facility. This absence of knowledge on the part of operating staff indicates a significant deficiency in the transfer of the technical basis for the facility from the constructor (Bechtel) to the operating contractor (Westinghouse). Efforts are now underway to correct these deficiencies through such efforts as developing as-built drawings and the conduct of air flow tests to explore the rationale for the placement of monitors for airborne radioactive material.

Residual issues from the FSAR review have continued to be closed through review of later material provided by Bechtel and by onsite verification during the RRI. However, the accident analysis section of the FSAR contains issues that remain open and will be so noted in the EH Safety Evaluation Report. The seismic issues cited in the May 4, 1989, EH report are closed based on EH consultant review of analysis at the San Francisco offices of Bechtel.

The remaining design issue, documented adequacy of the concrete waste shaft key, is being addressed through new analyses by Bechtel to replace and update earlier analysis that were apparently destroyed and confirmatory analysis by BNL for EH. In our view, those retrospective analyses will likely have to be supported by measurement of in situ stress in the inner surface of the concrete and monitoring of the key inside diameter for several years until its performance is sufficiently well understood for long-term acceptance. The likelihood of acceptable resolution appears good.

A fundamental management issue also remains open at this time; the adequacy of the DOE Quality Assurance (QA) program for the WIPP project. As presently structured, neither the dedicated QA staff, one person designated as the QA Manager, nor the low reporting level of the QA program meet the ANSI/ASME, NQA requirements espoused by DOE Orders. I believe that the adequacy of the DOE QA function at WIPP, particularly during the initial five-year experimental program will be a pivotal element in the successful demonstration of long-term isolation. Useful models for both DOE and the experimental program manager, Sandia National Laboratory, can be found in the evolving quality assurance programs associated with the high level waste program being conducted by the Office of Civilian Radioactive Waste Management. This issue deserves close and very high level attention.

The conduct of the RRI was based on 15 modules designed to sample a broad range of requirements based on commitments made in the FSAR, DOE Orders, the Design Validation Final Report (DVFR), and TSA criteria. The inspection was conducted by a twelve-member team of EH staff and consultants over a period of eight days. The team members reviewed the key technical documents that translated requirements into day-to-day operations, interviewed WIPP personnel, and inspected the facility buildings and systems.

As a result of the RRI, we have concluded that the physical plant at WIPP is very close to being ready for operation. The small number of exceptions appear to be addressed through satisfactory programs.

We have also concluded, however, that significant additional effort in ongoing staffing, training, procedure development, and documentation is necessary before EH could support a recommendation for startup. The areas most affected by these additional efforts are support functions such as radiological protection, maintenance, and quality assurance although additional training and qualification remain in operational areas as well.

Substantial efforts are underway in many of the areas needing improvement. For example, reorganization of the Radiation Protection Division was implemented during the week of our RRI, and we saw evidence of active recruitment efforts to staff this new organization. Although the as-built drawing effort noted above has not started, Westinghouse proposals for conduct of the program have been received and DOE/WPO has informed EH of its intent to make the availability of as-built electrical drawings to facilitate viable lockout and tagout procedures a first priority.

We have also briefly reviewed DOE/WIPP 89-011, Draft Plan For The Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration, April 1989. This report summarizes the five year experimental program that will develop the data necessary to demonstrate the ability of the WIPP facility to meet applicable regulations and agreements for long term isolation. A complete internal review of DOE/WIPP 89-011 will require strong expertise in the geoservices and related geo-engineering disciplines that is not presently represented by cognizant DOE staff in the field or at headquarters.

James P. Knight
Director
Office of Safety Appraisals

cc: w/o attachment
W. Kornack, ACNFS
W. Kranz, RL
J. Tillman, WIPP
A. Follett, DP-122

8.9 Summaries of Waterflows for the New Mexico Oil Conservation Division Districts 1 and 2

SUMMARY OF WATERFLOWS IN NMOCD DISTRICT 1 (NOVEMBER, 1978 TO PRESENT)

(SORTED BY LOCATION)

LIST NO.	DATE	OPERATOR	LEASE NAME/ WELL NO.	UNIT	T-R-SEC	OCD REP	REPORTER	DEPTH	[illegible]	BPH	[illegible]	ADDITIONAL REMARKS
1	[illegible]	[illegible]	[illegible]	K	06-37-33			[illegible]				[illegible] WATERFLOW ON [illegible] WELL AT [illegible].
2	[illegible]	[illegible]	[illegible]	I	09-10-32			[illegible]		4		DECREASED TO 2 [illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	11-16-34			[illegible]		60		[illegible]
4	[illegible]	[illegible]	[illegible]	C	11-16-35			[illegible]		180		[illegible]
5	[illegible]	[illegible]	[illegible]	L	15-16-35			[illegible]		[illegible]		
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]				WATER FLOW OUT SURFACE. [illegible]
7	[illegible]	[illegible]	[illegible]	F	[illegible]			[illegible]				[illegible]
8	[illegible]	[illegible]	[illegible]	M	[illegible]	CLEMENTS						PLUGGED WELL. [illegible]
9	[illegible]	Arco	[illegible]	E	[illegible]							[illegible]
10	[illegible]	Arco	[illegible]	J	[illegible]	[illegible]		[illegible]				[illegible]
11	[illegible]	[illegible]	[illegible]	N	[illegible]							BETWEEN [illegible] WATERFLOW [illegible]
12	[illegible]	Conoco	[illegible]	O	[illegible]							
13	[illegible]	Conoco	[illegible]	[illegible]	[illegible]							
14	[illegible]	[illegible]	[illegible]	C	[illegible]			[illegible]				[illegible] WATERFLOW ON [illegible]
15	[illegible]	[illegible]	[illegible]	M	[illegible]	CLEGG		[illegible]				LARGE WATER FLOW FROM SALT.
16	[illegible]	[illegible]		[illegible]	[illegible]			[illegible]				[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]				
18	No date	[illegible]	[illegible]	M	[illegible]							
19	[illegible]	Phillips	[illegible]	[illegible]	[illegible]			4300				[illegible]
20	[illegible]	Phillips	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			[illegible]
21	No date	Phillips	[illegible]	[illegible]	[illegible]							
22	[illegible]	Phillips	[illegible]	[illegible]	[illegible]			[illegible]		31		
23	[illegible]	Phillips	[illegible]	[illegible]	[illegible]					[illegible]		
24	[illegible]	Phillips	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	31		
25	[illegible]	Phillips	[illegible]	G	[illegible]			[illegible]		[illegible]		WELL [illegible] LOCATIONS FROM INJECTION WELL. [illegible]
26	[illegible]	Phillips	[illegible]	D	[illegible]			[illegible]		[illegible]		VAC AREA.
27	No date	Mobil	[illegible]	[illegible]	[illegible]			[illegible]				REPAIR JOB WATER [illegible]
28	[illegible]	Mobil	[illegible]	[illegible]	[illegible]							[illegible] LEAK REPORTED. [illegible]
29	[illegible]	Phillips	Lea [illegible]	L	[illegible]			[illegible]		40		[illegible]
30	[illegible]	Phillips	Lea	L	[illegible]			[illegible]				
31	[illegible]	Phillips	Lea [illegible]	[illegible]	[illegible]			[illegible]		[illegible]	150	
32	[illegible]	Phillips	[illegible]	[illegible]	[illegible]			[illegible]				CASING COLLAPSED [illegible]
33	[illegible]	Texaco	[illegible]	O	[illegible]	CLEGG		[illegible]		[illegible]	[illegible]	WATERFLOW [illegible]
34	[illegible]	Texaco	[illegible]	I	[illegible]	CLEMENTS		[illegible]	[illegible]	[illegible]		WATERFLOW [illegible] 10 BPH
35	[illegible]	Texaco	[illegible]	K	[illegible]	CLEMENTS		[illegible]	[illegible]	[illegible]		WATERFLOW [illegible] 15 BPH. [illegible] CSG. AND CEMENTED OFF
36	[illegible]	Texaco	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		WATERFLOW [illegible] BPH.
37	[illegible]	Texaco	[illegible]	M	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	WATERFLOW [illegible]
38	[illegible]	Texaco	[illegible]	N	[illegible]			[illegible]	[illegible]	[illegible]		WATERFLOW [illegible] TOTAL FLOW [illegible]
39	[illegible]	Texaco	[illegible]	N	[illegible]			[illegible]	[illegible]	[illegible]		WATERFLOW [illegible]
40	[illegible]	Texaco	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			WATERFLOW [illegible]
41	[illegible]	Texaco	[illegible]	[illegible]	[illegible]				[illegible]			[illegible] NO OTHER INFO AVAILABLE [illegible]
42	[illegible]	Texaco	[illegible]	O	[illegible]				[illegible]	800		WATERFLOW WHILE CEMENTING. [illegible]
43	[illegible]	Texaco	[illegible]	P	[illegible]	CLEMENTS		[illegible]		[illegible]	750	WATERFLOW [illegible]
44	[illegible]	Texaco	[illegible]	P	[illegible]	CLEMENTS		[illegible]		100		WATERFLOW [illegible]
45	[illegible]	Texaco	[illegible]	P	[illegible]			[illegible]	[illegible]	[illegible]	450	WATERFLOW [illegible]
46	[illegible]	Phillips	[illegible]	F	[illegible]				[illegible]	9		[illegible] WILL REPAIR.
47	[illegible]	Phillips	[illegible]	I	[illegible]			[illegible]	[illegible]			[illegible] PER MINUTE
48	No date	Phillips	[illegible]	J	[illegible]							
49	[illegible]	Texaco	[illegible]	N	[illegible]			[illegible]	[illegible]	2000	[illegible]	[illegible] CHANGE VALVE [illegible] FLOW LINE. [illegible]
50	No date	Phillips	[illegible]	[illegible]	[illegible]							
51	[illegible]	Phillips	[illegible]	[illegible]	[illegible]							DEVELOPED WATERFLOW FROM SURFACE CSG.

SUMMARY OF WATERFLOWS IN NMOCD DISTRICT 1 (NOVEMBER, 1978 TO PRESENT)

(SORTED BY LOCATION)

LIST NO.	DATE	OPERATOR	LEASE NAME/ WELL NO.	UNIT	T-R-SEC	OCD REP	REPORTED	DEPTH	DRLG OR PROD	BPH	PRESSURE	ADDITIONAL REMARKS
32	5/7/83	Arco	State [illegible]	M	17-35-33					40		WATER BROKE INTO CELLAR. HAULED [illegible] & APPEARED TO BE FLOWING ABOUT 4 BPH FROM AROUND SURFACE
33	5/7/83	[illegible]	[illegible]	M	17-35-33							
34	5/3/79	Phillips	East Vacuum Unit	N	17-35-33	CLEMENTS		2500'		20		
35	4/2/81	Amoco	[illegible]	A	18-34-04			1760'	DRLG	60		[illegible] CROSSFLOWED THEN FLOWED [illegible]
36	11/28/78	Amoco	Vac [illegible]	B	18-34-04			[illegible]	PROD	8-10	[illegible]	CASING LEAK AT [illegible] IN CELLAR. WATERFLOW @ 8-10 BPH. SIP=[illegible] PSI
37	[illegible]	Amoco	[illegible]	B	18-34-01			[illegible]	DRLG	[illegible]		WATERFLOW @ [illegible] @ [illegible] BPH
38	[illegible]	Amoco	[illegible]	B	18-34-01			1720'	DRLG	14		WATERFLOW @ [illegible] @ 14 BPH
39	No date	Amoco	[illegible]	B	18-34-01				PROD			
40	7/3/80	Amoco	[illegible]	C	18-34-01			1220'	DRLG	105		WATERFLOW @ [illegible] @ [illegible] BPH
41	[illegible]	Amoco	[illegible]	E	18-34-01							[illegible] WATERFLOW ON INTERMEDIATE. SAMPLED [illegible] PPM
42	No date	Texaco	[illegible]	M	18-34-01							
63	4/7/[illegible]	Texaco	[illegible]	M	18-34-01			[illegible]	DRLG	90		WATERFLOW @ [illegible] @ [illegible] BPH. NO OTHER INFORMATION AVAILABLE
64	7/7/[illegible]	Texaco	[illegible]	P	18-34-01			[illegible]	DRLG	145		[illegible]
65	[illegible]	Texaco	[illegible]	P	18-34-01				DRLG			WATERFLOW @ [illegible]. TOTAL FLOW=[illegible] BBL.
66	[illegible]	Texaco	[illegible]	G	18-34-02				PROD		[illegible]	WATERFLOW [illegible]. WILL REPAIR.
67	[illegible]	Amoco	[illegible]	[illegible]	18-34-[illegible]			[illegible]		90		HIT WATER FLOW ON DRLG. WELL AT [illegible] - [illegible].
68	No date	Phillips	[illegible]	I	18-35-[illegible]							[illegible] FLOW AT SHOE OF [illegible] ON [illegible] JOB
69	[illegible]	Texaco	[illegible]	A	18-35-[illegible]			[illegible]	DRLG	35		WATERFLOW @ [illegible] @ 35 BPH.
70	[illegible]	Texaco	[illegible]	A	18-35-[illegible]			[illegible]	DRLG	40		WATERFLOW @ [illegible] @ 40 BPH. [illegible]
71	[illegible]	Texaco	Central Vac Unit #[illegible]	D	18-35-06	CLEMENTS		2090'	DRLG	1000		WATERFLOW [illegible] 1000 [illegible].
72	[illegible]	Texaco	Central Vac Unit [illegible]	D	18-35-06			[illegible]	DRLG	[illegible]	[illegible]	WATERFLOW @ [illegible]
73	[illegible]	Texaco	Central Vac Unit #[illegible]	E	18-35-06	CLEMENTS		[illegible]	DRLG			WATERFLOW @ [illegible] BPH.
74	2/79	Texaco	Central Vac Unit #[illegible]	E	18-35-06	CLEMENTS			PROD			RE-ENTERED TO RELIEVE PRESS. FLOWING FROM [illegible]. [illegible]
75	4/79	Texaco	Central Vac Unit #100	F	18-35-06	CLEMENTS		[illegible]	DRLG	25	[illegible]	WATERFLOW @ [illegible] AND [illegible]. [illegible]
76	[illegible]	Texaco	Central Vac Unit #[illegible]	G	18-35-06	[illegible]		2015'	DRLG		[illegible]	WATERFLOW @ [illegible] @ 10 BPH. INC. TO [illegible] BPH. SIP=[illegible]. [illegible]
77	[illegible]	Texaco	Central Vac Unit #[illegible]	G	18-35-06			[illegible]	DRLG	18		WATERFLOW @ [illegible] AND [illegible]. TOTAL=[illegible] BPH. [illegible]
78	No date	Texaco	Central Vac Unit #[illegible]	G	18-35-06	CLEMENTS		[illegible]		30		
79	[illegible]	Texaco	Central Vac Unit #[illegible]	H	18-35-06				DRLG			WATERFLOW @ 4:00 A.M. RATE=[illegible] BPH. SIP=[illegible].
80	[illegible]	Texaco	[illegible]	H	18-35-06			[illegible]	DRLG	[illegible]		WATERFLOW @ [illegible] @ [illegible] BPH.
81	[illegible]	Texaco	Central Vac Unit #[illegible]	J	18-35-06			[illegible]	DRLG	14		WATERFLOW ON [illegible] WELL @ [illegible]. FLOWING 14 BPH. DRILLING AHEAD WITH NO INCREASE IN VOLUME. WILL [illegible]
82	[illegible]	Texaco	[illegible]	K	18-35-06			[illegible]	PROD	[illegible]		[illegible] FLOWED [illegible] BPH
83	[illegible]	Texaco	Central Vac Unit #[illegible]	L	18-35-06			[illegible]	DRLG	[illegible]		WATERFLOW @ [illegible] @ 10 BPH. INC. TO [illegible] BPH @ [illegible]. [illegible]
84	[illegible]	Texaco	Central Vac Unit #[illegible]	L	18-35-06	CLEMENTS		[illegible]	DRLG			WATERFLOW @ [illegible]. TOTAL FLOW= [illegible] BPH. SIP=[illegible]. [illegible]
85	[illegible]	Texaco	Central Vac Unit #[illegible]	M	18-35-06				PROD			WATERFLOW AFTER BOTTOM WAS PLUGGED OFF ON P&A.
86	[illegible]	Texaco	Central Vac Unit #[illegible]	N	18-35-06			[illegible]	DRLG	40-50	[illegible]	WATERFLOW ON DRILLING WELL @ [illegible] FLOWING 40-50 BPH. SIP=[illegible]. [illegible]
87	[illegible]	Texaco	Central Vac Unit #[illegible]	O	18-35-06			[illegible]	PROD	10	[illegible]	WATERFLOW @ [illegible] @ 10 BPH. SIP=[illegible]
88	[illegible]	Texaco	Central Vac Unit #[illegible]	G	18-35-07			[illegible]	DRLG	18		WATERFLOW @ [illegible] @ 18 BPH. SIP=[illegible]. [illegible]
89	[illegible]	Energy [illegible]	[illegible]	J	18-35-08			[illegible]				[illegible]
90	No date	[illegible]	[illegible]	I	18-35-[illegible]							
91	[illegible]	[illegible]	[illegible]	O	18-35-[illegible]			[illegible]		400-500		[illegible] FLOWING [illegible] BPH [illegible]. [illegible] DISPOSAL WELL.
92	[illegible]	[illegible]	[illegible]	P	18-36-31				DRLG	[illegible]		
93	[illegible]	[illegible]	[illegible]	B	18-36-37				DRLG			[illegible] DRLG DEPTH UNKNOWN. [illegible] BPH. COMPLETED [illegible]. INTEND TO P&A [illegible].
94	[illegible]	[illegible]	[illegible]	D	18-36-37			[illegible]	DRLG	[illegible]	[illegible]	
95	[illegible]	[illegible]	[illegible]	F	19-33-33	CLEMENTS		[illegible]		[illegible]		
96	No date	Arco	[illegible]	G	19-34-[illegible]							
97	[illegible]	Amerada	[illegible]	B	19-37-32			[illegible]				
98	[illegible]	Amerada	[illegible]	C	19-37-32	[illegible]		[illegible]				
99	[illegible]	[illegible]	State H Com	K	19-37-32			[illegible]				LOCATED WATER FLOW AT [illegible]. [illegible]
100	No date	Texaco	[illegible]	B	19-38-08							
101	[illegible]	Amerada	[illegible]	P	20-33-[illegible]			[illegible]		500		
102	[illegible]	Amerada	[illegible]	G	20-33-[illegible]			2511'		500		

SUMMARY OF WATERFLOWS IN NMOCD DISTRICT 1 (NOVEMBER, 1978 TO PRESENT)

(SORTED BY LOCATION)

WF NO.	DATE	OPERATOR	LEASE NAME/ WELL NO.	UNIT	T-R-SEC	[illegible]	[illegible]	DEPTH	DRLG OR PROD	BPH	PRESSURE	ADDITIONAL REMARKS
103	11/2/81	Aztec Oil	Jordan [illegible] #19	E	30-13-16			3419				DRILLING.
104	8/7/81	[illegible]	[illegible]	G	29-13-25			2750				[illegible]
105	No date	Tenneco	[illegible]	C	30-13-35					1700		APPROXIMATELY 200 YDS. [illegible]
106	9/25/79	Arco	[illegible] Gas Com #1	I	30-12-08							
107	1/6/80	Tenneco	[illegible]	P	30-12-11				PROD			[illegible] FLOW [illegible] SECTION, CSG. [illegible]
108	3/30/79	Tenneco	[illegible]	G	30-12-12	[illegible]			PROD	28	10	TESTED BRADENHEAD. FLOWED [illegible]
109	9/10/81	Tenneco	[illegible] #12	G	30-12-12				DRLG			WATERFLOW @ [illegible] ABOVE CEMENT.
110	1979	Tenneco	[illegible]	G	30-12-13							WATERFLOW HAD TO [illegible]
111	No date	Tenneco	[illegible] #7	I	30-12-13							
112	1/27/84	Tenneco	[illegible] #12	C	30-12-14			[illegible]	DRLG	4		WATERFLOW @ [illegible] WATERFLOW AREA.
113	6/20/84	Tenneco	[illegible] #13	[illegible]	30-12-15			[illegible]	DRLG	28	135	WATERFLOW @ [illegible]
114	3/21/80	Amoco	[illegible]	C	30-12-20							[illegible]
115	3/1/79	Conoco	[illegible]	H	[illegible]	[illegible]		2700		20-30		
116	[illegible]	Conoco	[illegible]	O	[illegible]							P.W. PLUG BACK
117	[illegible]	Conoco	[illegible]	J	[illegible]							WF FROM PLUGGED WELL. [illegible]
118	[illegible]	Phillips	[illegible]	E	[illegible]			[illegible]	DRLG	6-10	64	[illegible]
119	[illegible]	Amoco	[illegible]	K	[illegible]				PROD			[illegible]
120	[illegible]	[illegible]	[illegible]	H	[illegible]							WATER FLOW FROM SURFACE CSG. [illegible]
121	[illegible]	Yates Petroleum	[illegible] #1	P	[illegible]			[illegible]	DRLG	20-30		[illegible]
122	[illegible]	[illegible]	[illegible]	B	[illegible]			[illegible]	DRLG			FLOWED [illegible]
123	[illegible]	Sun	[illegible]	A	[illegible]			[illegible]		24		
124	[illegible]	Amoco	SRCU #25	M	[illegible]							WATERFLOW OUT SURFACE CSG. [illegible] OUTSIDE SURFACE CSG.
125	[illegible]	Amoco	SRCU #28	H	[illegible]							
126	[illegible]	Amoco	SRCU #29	K	[illegible]							
127	[illegible]	[illegible]	Paradox Unit #35	N	[illegible]						[illegible]	WATERFLOW ON SURFACE PIPE & INTERMEDIATE PIPE.
128	[illegible]	Sohio	[illegible]	E	[illegible]							DUAL.
129	No date	Gulf	Hughes	D	[illegible]							
130	[illegible]	Amerada	Hugh #18	E	[illegible]							BLEW MUD OUT SURFACE. HAD GAS PRESSURE & WF. WILL DO GAS ANALYSIS.
131	[illegible]	Amerada	[illegible] #11	N	[illegible]							WATERFLOW FROM SURFACE - [illegible] AROUND SURFACE PIPE.
132	[illegible]	Gulf	[illegible]	A	[illegible]			[illegible]	DRLG	15		[illegible]
133	[illegible]	Gulf	Cole A #[illegible]	I	[illegible]			[illegible]			[illegible]	
134	[illegible]	[illegible]	[illegible]	C	[illegible]	[illegible]						
135	[illegible]	[illegible]	[illegible]	E	[illegible]			[illegible]				[illegible]
136	[illegible]	[illegible]	[illegible]	F	[illegible]					[illegible]		[illegible]
137	[illegible]	Arco	[illegible]	H	[illegible]			[illegible]		[illegible]	[illegible]	[illegible]
138	[illegible]	Marathon	[illegible]	K	[illegible]			[illegible]	DRLG			[illegible]
139	[illegible]	[illegible] Partnership	[illegible]	G	[illegible]	[illegible]		[illegible]				SALT WATER FLOW [illegible]
140	[illegible]	Sun	[illegible]	D	[illegible]			[illegible]			[illegible]	[illegible]
141	[illegible]	[illegible]	[illegible]	D	[illegible]			[illegible]				[illegible]
142	[illegible]	[illegible]	[illegible]	O	[illegible]			[illegible]		[illegible]		
143	[illegible]	[illegible]	[illegible]	A	[illegible]			[illegible]	DRLG	[illegible]		[illegible] P&A.
144	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							HIT WF.
145	[illegible]	Anadarko	LMPSU [illegible]	M	[illegible]			[illegible]				[illegible]
146	[illegible]	Anadarko	LMPSU [illegible]	I	[illegible]			[illegible]				[illegible]
147	[illegible]	Anadarko	LMPSU [illegible]	A	[illegible]			[illegible]		[illegible]		[illegible]
148	No date	Anadarko	LMPSU [illegible]	A	[illegible]							
149	[illegible]	Anadarko	LMPSU [illegible]	F	[illegible]			[illegible]		[illegible]		
150	No date	[illegible]	[illegible]	I	[illegible]							
151	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	DRLG	[illegible]		WATERFLOW @ [illegible]
152	[illegible]	Amerada	[illegible]	G	[illegible]			[illegible]		[illegible]		[illegible]
153	[illegible]	[illegible]	[illegible]	N	[illegible]			[illegible]		[illegible]		[illegible]

SUMMARY OF WATERFLOWS IN NMOCD DISTRICT 1 (NOVEMBER, 1978 TO PRESENT)

(SORTED BY LOCATION)

LIST NO.	DATE	OPERATOR	LEASE NAME / WELL NO.	UNIT	T-R-SEC	OCD MTP	REPORTS	DEPTH	DRLG OR PROD	BPH	PRESSURE	ADDITIONAL REMARKS
154	11/17/82	Texaco	[illegible] Fed NCT [illegible]	C	23-36-31			1075	DRLG	40	601	WATERFLOW @ 3000' @ 40 BPH. [illegible]
155	10/18/84	Amoco	[illegible] Fed NCT [illegible]	O	23-36-31			1685	DRLG	1050		WATERFLOW @ 1385' @ 1050 BPH [illegible]
156	12/10/79	Amoco	[illegible]	E	23-35-07							
157	7/4/83	Sun	Emery King NW [illegible]	C	23-36-01							CASING COLLAPSED [illegible]
158	1/13/80	Amoco	[illegible]	C	23-36-07							INT. REPAIR CASING. [illegible]
159	11/14/79	A. Gregory	[illegible]	B	23-36-06							TROUBLE OF SALT WATER COMING OUT SURFACE. WILL PERFORATE @ 1260' & SQUEEZE.
160	[illegible]	[illegible]	[illegible]	M	23-37-01			1640	DRLG	400		SHUT IN PRESSURE 1000 PSI [illegible]
161	10/10/81	[illegible]	[illegible]	M	23-37-09			2600		1000		DECREASED TO 300 BPH IN 48 HOURS
162	4/9/75	Texaco	[illegible]	9	23-37-00			3049	DRLG	460	625	WATERFLOW ON [illegible]
163	1/10/85	Texaco	[illegible] A [illegible]	J	23-37-08			1800		750		WATERFLOW @ [illegible]
164	7/15/80	Texaco	[illegible]	H	23-37-11				DRLG			WATERFLOW @ 2700' @ 85 BPH.
165	4/15/77	Texaco	[illegible]	K	23-37-14			2600	DRLG			NOTICED 3000'. [illegible]
166	No data	Texaco	[illegible]	H	23-37-04			5040	DRLG	80		SHUT IN PRESS 500 PSI.
167	11/24/73	Texaco	[illegible]	B	23-37-03			1444	DRLG	1200		WATERFLOW @ 1444' @ 1200 BPH. PRESS=500 PSI
168	[illegible]	Texaco	[illegible]	G	23-37-04			2080	DRLG	600		WATERFLOW @ 2080' @ 600 BPH. SIP - [illegible] PSI.
169	[illegible]	Texaco	[illegible]	D	23-37-09			1307	DRLG	95	850	WATERFLOW @ 1307' @ 95 BPH. [illegible]
170	[illegible]	Texaco	[illegible]	K	23-37-09			1315	DRLG	100		WATERFLOW @ 1315' @ 100 BPH. WATERFLOW @ [illegible] @ 1200 BPH.
171	[illegible]	Texaco	[illegible]	L	23-37-09			1507	DRLG	85		WATERFLOW @ 1507' @ 85 BPH
172	No data	Texaco	[illegible]	L	23-37-09			1570	DRLG	1000	650	WATERFLOW @ 1570' @ 1000 BPH. [illegible]
173	[illegible]	[illegible] Oil Co	[illegible]	5	23-37-13			1580		100		
174	[illegible]	Texaco	[illegible]	F	24-37-[illegible]	[illegible]						WATERFLOW [illegible]
175	[illegible]	Texaco	[illegible]	C	24-36-[illegible]				DRLG			FLOWING [illegible]
176	[illegible]	Gulf	[illegible]	M	24-36-10							[illegible]
177	[illegible]	Texaco	[illegible]	P	24-36-32			1400	DRLG			WATERFLOW @ [illegible]. WATERFLOW @ 2000' @ 20 BPH.
178	[illegible]	Gulf	[illegible]	I	25-10-16							[illegible]
179	[illegible]	[illegible]	[illegible]	L	26-10-16			[illegible]	DRLG	est. 1260		[illegible]
180	[illegible]	[illegible]	[illegible]	A	26-37-15					[illegible]		
181	[illegible]	Amoco	[illegible]	C	26-37-37					[illegible]		WATERFLOW @ [illegible] (NO REPORT TO OCD).
182	[illegible]	Amoco	[illegible]	F	26-37-37			1311	PROD		400	WATERFLOW ON BRADENHEAD (NO REPORT TO OCD)
183	[illegible]	Texaco	[illegible]	I	26-37-37					900		WATERFLOW [illegible] (NO REPORT TO OCD).
184	1/79	Texaco	[illegible]	G	26-37-37			1050				WATERFLOW [illegible] (NO REPORT TO OCD).
185	[illegible]	Texaco	[illegible]	H	26-37-37					650		REPORTED TO OCD [illegible]
186	[illegible]	Texaco	[illegible]	H	26-37-37					450		WATERFLOW [illegible] (NO REPORT TO OCD)
187	[illegible]	Texaco	[illegible]	I	26-37-37					[illegible]		WATERFLOW [illegible] (NO REPORT TO OCD)
188	[illegible]	Texaco	[illegible]	I	26-37-37					75		WATERFLOW [illegible] (NO REPORT TO OCD)
189	[illegible]	Texaco	[illegible]	K	26-37-37					1100		WATERFLOW [illegible] (NO REPORT TO OCD)

WATERFLOW INFORMATION

1. Pogo Producing Co. 9/30/92 ; Federal Red Tank 34 #1-34-22-32 Drilling 3000' Flowed 800 bbls - High in H_2S, - Don Riggs 713-297-5045 10/23/92

2. Texaco Expl & Prod. 4-7-93; NMR NCT-3 #5- Drilling @ 1864' 90 BPH No other information available.

3. Texaco Expl & Prod. 4-9-93; Ellen Sims #9-3-23-37 Drilling @ 3049' Flowing 660 BPH @ 825# 4:00 AM -5-10-93 down to 440; 5/11/93 James Elliott down to approx. 70 BPH since 5-10-93 PM - setting 8 5/8" intermediate @ 3750'.

4 Texaco Expl & Prod. ; BF Harrison B #9 9-23-37 Drilling @ 1571' Flowed 1000 BPH Shut in Pressure 600#

5. Samedan; Sarah B #3-M 1-23-37 Drilling @ 1590' 600 BPH +-; Shut In Pressure 1000 Est. Vol 92000 +-.

6. Texaco Expl & Prod; R. R. Sims A #3 - 4-23-37; Drilling @ 2240' ; Flowed 80 BPH, Shut In Pressure 600 psi.

7. Texaco Expl & Prod: 11/24/93 - 9:00 AM; G. W. Sims #3- B - 9-23-37; Drilling @ 1444' Flowed 1200 BPH; Pressure 500 psi; Flowed down in 6 hours - 12-1-93 Drilling @ 5600', no further problems.

8. Texaco Expl & Prod; 5/17/94; WDDU #131 -32-24-38; Drilling @ 1420' ; Flowed 7 BPH @ 2000' 20 BPH.

9. Texaco Expl & Prod; 5/13/94; WDDU #146 - C 32-24-38; Drilling @ ?; Flowed 70 BPH.

10. Texaco Expl & Prod; 5/25/94; B F Harrison B #25 - C - 9-23-37; Drilling @ 2065'; Flowed 600 BPH; Shut In Pressure 875 down to 400 BPH @ 2:35 puff H_2S down to 1 PPM @ 2:35 Drilling ahead.

11. Texaco Expl & Prod; 5-1-95; R.R. Sims B #1 - 4-23-37; Drilling @ 1709'; Flowed 390 BPH; Pressure not recorded 5/1/94 up to 800-1000 BPH - Flow heavy for approx 1 hour then slacks off - Drilling not delayed and drilling at 3282' approx. 7:45 AM 5/1/95.

12. Phillips Petro. Co.; 7/1/96; Hale 25 25-17-34; Drilling @ approx. 4800' - Poss hit earlier no pressure - 10 BPH up to 20 BPH and back to 10 BPH - cont. Drilling set production casing 7/2/96.

13 Nearburg Prod. Co.; 10/6/97; Madura Federal #5 - E- 28-19-33; Drilling @ 8549 10-6-97; No record of pressure or volumes 100 BPH per Jack - Hit @ 1300' swedge and squeezed hit again 1900#.

14. Texaco Expl & Prod.; 10/25/97; State AN #12 ; Drilling @ 2985; No pressure recorded

60 BPH - down to 45 BPH @ 11 am - 10/27/97 Depth 3380' will set intermediate @ 3506.

15. John H. Hendrix 12/2/97; Boyd #7 - 23-22-37 Drilling; No pressure recorded 700 BPH.

TOWN	RANGE	SEC	UNITLTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	ANH TOPS
1	2	36	E	Patoamto Co	Summer 36	1		394'	
1	28	6	H	Chevron/Bach Petro. Inc.	Cave St.	2	1788'-150BWPD		
5	26	16	G	Yates Petro. Corp.	Paulerly PV ST	5			
5	26	34	E	Meabourne Oil Co.	Pecos Slope 34	1			
6	26	20	D	Yates Petro. Corp.	Hancock AHC Com.	3	28-30 bbls Hrs 58 Post Flash		
6	26	32	D	Yates Petro. Corp.	Tamarack DF St.	1		597'	
6	26	32	E	Yates Petro. Corp.	Tamarack OF St.	2			
6	26	32	E	Yates Petro. Corp.	Tamarack OF	3		718'	
7	22	1	P	Mesa Petro. Corp.	Haley Com.	2			
7	22	2	F	Emmn Corp.	New Mexico CS St.	1		95'	
7	22	12	A	Yates Petro. Corp.	Haley Com.	3			
7	23	3	M	Yates Petro. Corp.	Barstow SN St.	1		313'	
7	23	8	M	Mesa Petro. Corp.	M.E.C. Com.	1			
7	23	10	L	Mesa Petro. Corp.	Round Top St.	6		480'	
7	23	20	D	Mesa Petro. Corp.	McKnight Com.	1		175'	
7	23	32	A	Yates Petro. Corp.	Rambler AGU St.	1			
7	24	8	J	Yates Petro. Corp.	Salmon Canw NR	1			
7	24	11	P	Yates Petro. Corp.	Red Bluff St.	1			
7	24	27	E	Yates Petro. Corp.	West Dixon NK St.	1			
7	24	36	P	Yates Petro. Corp.	Snakeweed SO St.	1			
7	25	2	P	Yates Petro. Corp.	Canelo BH St.	1			
7	25	7	C	YATES PETRO. CORP.	HILLTOP HQ ST	1			
7	25	11	A	Mesa Petro. Corp	Burns Com.	2			
7	25	11	I	Mesa Petro. Corp.	Burns Com.	1			
7	25	17	P	Yates Petro. Corp.	Cocklebur RD	1			
7	25	23	A	Yates Petro. Corp.	Pearl ANS	1			
7	25	27	I	Yates Petro. Corp.	Pepalnte QI ST Com.	5			
7	25	30	F	Yates Petro. Corp.	Skink SK St.	4			
7	25	5	F	Mesa Petro. Corp.	Neal Com.	1			
7	26	6	B	Yates Petro. Corp.	Crandell UD	2			
7	26	16	K	Sanders Petro. Corp.	McKey Sweeden	2	1850'-20 BPM		
8	23	33	D	Yates Petro. Corp.	Middle Creek St.	1		95'	
9	23	5	K	Mesa Petro Corp.	Ned St.	1			
9	23	5	O	Mesa Petro Corp.	Ned St.	2		300'	
9	23	9	L	Mesa Petro. Corp.	Ned St	3			
9	23	11	H	Yates Petro. Corp.	Whipsel ZN St	1			
10	25	2	H	Yates Petro. Corp.	Elickson KY	1		320'	
10	25	8	H	Yates Petro. Corp.	Hargrove AIH	1			
10	25	16	M	Yates Petro. Corp.	Bluer Lake FX St.	1			
10	25	17	C	Yates Petro. Corp.	Eakin AKB Com.	1			
10	25	17	H	Union Inc.	Cannon Fed	3			
10	25	17	H	Yates Petro. Corp.	Cannon XF	1		402'	
10	25	27	B	Yates Petro. Corp	Unich AFF	1	617'-18 20 BWPM Gyp Wtr 9000 ppm clo		

RECEIVED
SEP 5 1996
ENVIRONMENTAL EVALUATION GROUP

TOWN	RANGE	SEC	UNIT LTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
11	24	18	J	Wallace oil @ Gas Inc.	Hain	1			
11	25	3	M	Wallace OIL & Gas	Britt	1			
11	25	3	M	Wallace Oil & Gas	Britt	2	830' Fresh Water		Hondo SA Perf. 858'-86'
11	25	4	F	Fred Pool Drlg co.	Hondo River Farm	1			
11	25	8	J	Wallace oil @ Gas Co.	Payton	1			
11	25	10	D	Wallace oil @ Gas Co.	Marshall & Winston	1	W.F. @ 876' 5800Gal./Min. 2800ppmClu.		
11	25	20	P	Wallace oil @ gas Inc.	Pomona	1		800'	
11	25	29	F	William R. Mason	Stovall Com.	1			
11	28	14	L	YATES PETRO. CORP.	Mccaw bt	7	0	750	
12	23	26	E	Phillips Petro. Corp.	N.M. 26 St.	1		1032'	
12	28	3	L	Nuthetz Oil Co.	Bogle	1	W.F. @ 30' .0626 Stream No Psi.		
12	28	3	L	Nuthetz Oil co.	Bogle	1	1/16" Stream No PSI @ 30' Cmted off		
13	28	8	N	Petroit Corp.	Capt Johnson	1			Top S.A. 680'
13	26	36	J	Clements Energy Inc.	New. Mex. 36 St.	2			
14	24	9	I	The Superior Oil Co.	Ivy League Fee	1			
14	26	30	J	Clements Energy Inc.	Bird	1y			
14	26	12	K	Southland Royalty Co.	Hagerman West 22	1			
14	26	23	M	Shenandoah Oil Co.	Rhodes	1			
14	26	33	E	Lyn Petro. Corp.	Drumm Com.	1			
14	26	33	G	Clements Energy Corp.	Drumm Com.	1			
14	26	36	J	Clements Energy Corp.	King 36 Com.	1			
15	25	28	F	Yates Petro. Corp.	Carol Jackson RO	1		900'	Top S.A. 602'.
16	28	32	F	Mesa Petro. Corp.	Mesa State Com.	2	1167'-800BPH Brine FLOW SI PSI 650#		
15	28	32	K	Mesa Petro. Corp.	Mesa State Com.	4	468' 160 BWPH		
16	17	6		J. Cleo Thompson	State A	6		Air Dil	
16	30	5	J	Petro. Devel. Corp.	Marathon Fed.	1	2350' 6" Stream.		
16	30	9	C	Yates Petro. Corp.	Sidey PY Fed.	1	2737'-10BPM		
16	30	11	J	Yates Petro. Corp.	Strange "PZ" Fed.	1	2950' 3BWPM SI PSI 1350#.		
17	17	3	F	J. Cleo Thompson	State A-3	1		412'	Open. LC @ 1210' Csg Was Set in Orig Break.
17	28	13	L	Yates Petro. Corp.	Aichen Frey DM	2			
17	26	14	H	Yates Petro. Corp.	McCaw BT	7		750'	
17	28	14	M	Yates Petro. Corp.	Morris Estate DC	6		723'	
17	28	14	P	Yates Petro. Corp.	Winters DY	4		740'	
17	25	15	P	Yates Petro. Corp.	Morris Estate DC	7		715'	
17	25	16	P	Yates Petro. Corp.	Morris Estate DC	7		715'	
17	26	22	H	Yates Petro. Corp.	J Lary J	3			
17	25	23	I	Yates Petro. Corp.	Mitchell JB	6			
17	25	23	K	Yates Petro. Corp.	Bissler AV	6			
17	25	23	M	Yates Petro. Corp.	Bissler AV	30			
17	25	27	A	Yates Petro. Corp.	Ingram Jackson BV	10			
17	26	36	O	Yates petro. Corp.	Powell DG				
17	26	38	I	Yates Petro. Corp.	Aroo LC St.	2			
17	26	10	P	Mewbourne Oil Co.	Sullivan	1			

TOWN	RANGE	SEC	UNIT/LTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
17	28	14	E	Mewbourne Oil CO.	Haldeman	1			
17	28	14	M	Mewbourne oil Co.	Vogel	1			
17	28	15	I	Yates Petro. Corp.	Cyfiell Fed. FD	2			
17	28	19	K	Medallion Prod.Co.	Lewis 19	1			
17	28	26	N	Barbara Fasken	State 26	1			
17	28	27	J	Marbob Energy Corp.	NG Phillips St.	25	494-88' 1.50Gal/Min.		
17	28	35	O	Mewbourne Oil CO.	State BX	1	570'-516 BWPD		
17	29	12	P	Marbob Energy Corp.	Burch Keely Ut.	1	2430 !		
17	30	1	A	Ray Westall	Artesia Petro.Fed.	4	2385' 8000BPD si psi-950#		
17	30	2	B	J.Cleo Thompson	Moyer ST.	5	2530' 3" Stream		
17	30	16	I	Fowler Oil & Gas Co.	Dale H. Parke "D"	2	3317' 11000BPD		
17	30	34	G	Anadarko Petro. Corp.	Arnold Fed. Com.	1	6185'284 BWPD		Glorieta 4700'-5000'
17	31	3	G	Devon Energy Corp.	H.E. West A	32	3549' 1 BPH		
17	31	3	J	Devon Energy Corp.	H.E. West "B"	76	33 BWPH @ 3550'		
17	31	3	L	Devon Energy Corp.	H.E. West B	33	3227' 14 BPH		
17	31	3	O	Devon Energy Corp.	H.E. West "B"	86	18 BWPD @ 3637'		
17	31	4	E	Devon Energy Corp.	H.E. West B	73	3225' 7.30 BPH		
17	31	6	D	Devon Energy Corp.	J.L. Keel B	69	2800'-3000' 14 BPH		
17	31	6	N	Devon Energy Corp.	J.L. KEEL B	64	2910' 2.3 BPH		
17	31	6	B	Socorro Petro. Co.	J.L. Keel "B"	33	2500'-33CBPH		
17	31	7	A	Devon Energy Corp.	J.L. Keel A	23	3000'-3100' 38 BPH		
17	31	7	H	Devon Energy Corp.	J.L. Keel A	33	1800' 50 BPH		
17	31	7	J	Devon Energy Corp.	J.L. Keel A	137	730' 10-15 BPH		
17	31	8	F	Devon Energy Corp.	J.L. Keel B	90	3800' 23 BPH		
17	31	8	I	Devon Energy Corp.	J.L. Keel B	57	1297' 48 BPH		
17	31	8	J	Devon Energy Corp.	J.L. Keel B	78	900' 17 BPH		
17	31	8	M	Devon Energy Corp.	J.L. Keel B	63	1400' 3.8 BPH		
17	31	9	G	Devon Energy Corp.	H.E. West B	64	2960' 43 BPH		
17	31	9	O	Devon Energy Corp.	H.E. West B	84	3502' 2 BPH		
17	31	9	P	Devon Energy Corp.	H.E. West B	72	3200' 1.8 BPH		
17	31	10	D	Devon Energy Corp.	H.E. West B	66	3800'-4190' 23 BPH		
17	31	10	E	Devon Energy Corp.	H.E. West B	81	3593' 5 BPH		
17	31	10	F	Devon Energy Corp.	H.E. West B	80	3877' 16 BPH		
17	31	10	G	Devon Energy Corp.	H.E. West B	47	3313' 1.5 BPH		
17	31	10	I	Devon Energy Corp.	H. E. West "B"	70	4010' 1.50 BPH		
17	31	17	E	Devon Energy Corp.	Hudson Fed.	8	20-147 BPH @ 590'		T.Rustler @ 367'T.Salado @ 500'B.Salado @ 1326'
17	31	17	M	DEVON ENERGY CORP.	TURNER B	116	2708'-60 BPH		
17	31	18	E	Devon Energy Corp.	C.A. Russell	15	4 BWPD @ 738'		
17	31	18	I	Devon Energy Corp.	Turner "A"	52	47 BWPD @ 1003'		
17	31	18	L	Devon Energy Corp.	Turner A	36	17 BWPD @ 2625'		
17	31	18	N	Devon Energy Corp.	Turner A	39	18 BWPD @ 2842'		
17	31	18	P	Devon Energy Corp.	Turner "A"	40	47 BWPD @ 1003'		
17	31	18	A	Devon Energy Corp.	Hudson Fed.	11	7 BPH @ 3080'		

TOWN	RANGE	SEC	UNITLTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
17	31	18	A	Devon Energy Corp.	Hudson Fed.	7	8 BPH @ 1905'		
17	31	18	A	Devon Energy Corp.	C.A. Russell	17	778'-808' 142 BWPH		
17	31	18	I	DEVON ENERGY CORP	TURNER A	55	22 BPD @ 3061'		
17	31	18	M	DEVON ENERGY CORP.	TURNER A	41	2578'-43 BPH		
17	31	18	N	DEVON ENERGY CORP	TURNER A	59	27 BPD @ 2811'		
17	31	18	O	Devon Energy Corp.	Turner A	42	2285' 21 BWPD		
17	31	18	O	DEVON ENERGY CORP	TURNER A	58	86 BPD @ 2696'		
17	31	18	P	DEVON ENERGY CORP.	TURNER A	44	758'-30 BPH		
17	31	18	P	DEVON ENERGY CORP.	TURNER A	43	803'-88 BPH		
17	31	19	H	Devon Energy Corp.	Turner "A"	50	482'90BWPD, 1186' 200BWPD, 1388' 240BPD		
17	31	19	I	Devon Energy Corp.	Fren Oil Co.	24	14 BWPD @ 1440'		
17	31	19	C	Devon Energy Corp.	Turner A	46	81 BWPH @ 1876'		
17	31	18	G	Devon Energy Corp.	Turner A	48	14 BPH @ 1320'		
17	31	18	C	DEVON ENERGY CORP	TURNER A	57	11 BPD @ 1614'		
17	31	18	F	Devon Energy Corp.	Turner A	48	47.8 BWH @ 1326'		
17	31	18	G	Devon Energy Corp.	Turner A	49	800' 143 BWPD		
17	31	19	H	Devon Energy Corp.	Turner A	47	3.0 BPH @ 1080'		
17	31	19	J	Devon Energy Oper. Corp.	Turner A	51	1402'-1408' 71 BWPH		
17	31	19	J	DEVON ENERGY CORP	FRIESS FED	4	172 BPD @ 718'		
17	31	20	M	DEVON ENERGY CORP	TURNER A	118	57 BPD @ 882'		
18	25	10	L	Yates Petro. Corp.	Thistle AKF	1		693'	
18	25	34	K	Yates Petro. Corp.	Rio Penasco RT	2		770'	
18	26	1	D	Sandra Falken	Higgins Trust "1"	1			
18	26	18	W	Yates Petro. Corp.	West Dayton AJR	1		765'	
18	26	18	A	Yates Petro. Corp.	Vandiver CN Com.	2		894	
18	26	22	H	Yates Petro. Corp.	Lawrence ADZ	2			
18	26	22	M	Yates Petro. Corp.	Rayburn Fz	2		60'	
18	26	28	C	Yates Petro. Corp.	Dayton FH	2			
18	28	34	C	Yates Petro. Corp.	Allied Lee ABH	2			
18	26	34	C	Yates Petro. Corp.	Allied Lee ABH	2			
18	26	34	C	Yates Petro. Corp.	Allied Lee ABH	2			
18	27	7	K	Devon Energy Corp.	West Red Lake Ut.	56			
18	27	7	D	Devon Energy Corp.	West Red Lake Ut	59			
18	27	7	F	Devon Energy Corp.	West Red Lake UT	57			
18	27	7	F	Devon Energy Corp.	West Red Lake Ut	52			
18	27	7	I	Devon Energy Corp.	West Red Lake Ut	38			
18	27	7	O	Devon Energy Corp.	West Red Lake UT	42			
18	27	26	I	SDK Resources Inc.	Artesia Metex	64			
18	28	8	A	Anadarko Petro. Corp.	Ballard GSAU TR. 5	15	1385' 214 BPH SI PSI 180#		
18	28	22	G	Primier Oil & Gas Co.	Yates Primier Fed.	3	1566' 10# Brine		
18	29	22	K	J&W Inc.	Empire 22 Fed. Com.	1	560' 28000 BWPD		
18	29	22	K	Ray Westall	Dunton Fed.	6	835' 5000 BPD		
18	29	22	O	Premier	Yates Premier Fed.	1	1543' 10 Gal./Min.		

TOWN	RANGE	SEC	UNIT LTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
18	30	2	N	MEWBOURNE OIL CO.	LOCO HILLS ST.	4	1616 3BPM 450 si PSI BRACKISH WTR		
18	30	2	O	Mewbourne Oil Co.	Cadet Paseka St. 2	3	838 40 BWPH 51 PSI 350# 10.6 Brine		Salt Section 720'-1500'
18	24	4	N	Yates Petro. Corp.	Rancheria AMH St. Com.	1		79'	
19	24	33	E	Yates Petro. Corp.	Agave AAJ St.	3		90'	
18	25	4	O	Yates petro. Corp.	Bradshaw	2			
19	25	4	O	Anadarko Petro. Corp.	Bradshaw	2			
19	25	8	I	Yates Petro. Corp.	THOMAS AJJ	4		470'	
19	25	8	I	Yates Petro. Corp.	thomas AJJ	6			
19	25	8	J	Yates Petro. Corp.	Thomas AJJ	3			
19	25	8	P	Yates Petro. Corp.	Roy AET	5			
19	25	8	E	Yates Petro. Corp.	Marshall Aph	1			
18	25	9	F	Yates Petro. Corp.	Marshall APH	1			
18	25	8	F	Yates Petro. Corp.	Marshall APH	1			
18	25	8	G	Yates Petro. Corp.	Parrick API	2			
19	25	16	C	YATES PETRO. CORP.	APARUO APA ST COM.	6		60'	
19	25	15	O	Yates Petro. Corp.	Aparejo AMP	1			
19	25	16	K	Yates Petro. Corp.	Amole Amm St. Com.	2			
19	25	17	K	Conoco Inc.	Baldwin 17	17			
19	26	20	H	Yates petro. Corp.	Hopper AMP	3			
19	26	20	M	Yates Petro. Corp.	Fairoil Alt Com.	1			
19	25	21	E	Yates Petro. Corp.	Hopper AMP	2			
19	25	21	M	Yates Petro. Corp.	Pavoh AIZ	10		384	
19	26	24	E	Nearburg Prod. Co.	Fairchild 24	1		66'	1" from 100' to 66' Pose. void 400' 100' Quar. wil
18	25	27	E	Nearburg Prod. Co.	South Boyd 27	3			
18	26	27	L	Nearburg Prod. Co.	South Boyd 27	4			
19	25	28	B	Yates Petro Corp.	Hinkle ALD	2		410'	
18	25	28	G	Yates Petro. Corp.	Hinkle AId	1		63'	
18	26	28	J	Yates Petro. Corp.	Teskrit AQT	1		347'	
18	26	28	J	Nearburg Prod. Co.	State K	2		190'	
19	25	28	D	Yates Petro. Corp.	Teckrit AQT	3			
18	26	29	D	Yates Petro. Corp.	Voight AJD Com.	1			
19	25	32	A	Conoco Inc.	Savannah St.	1			
19	25	32	A	Conoco Inc.	Savannah State	1		366'	
19	25	33	A	MEWBOURNE OIL CO	STATE B	2			
19	26	18		Nearburg Prod. Co.	Lakewood Farms 18	1			
19	26	1	B	Bass Enterprises Production Co.	Merchant State	3	1390' 146 BWPH 10# Brine 200#S PSI		
19	30	14	K	Texaco Explo. & Prod. Co.	Remuda Basin St.	2			Top Salt 837' Base Salt 2875'
20	24	1	A	Yates Petro. Corp.	Foster AN	3			
20	24	1	B	Yates Petro. Corp.	Foster AN	1		825'	
20	24	1	G	Yates Petro. Corp.	Mobil AOB	1		247'	
20	24	2	M	Yates Petro. Corp.	Candelila AKD	2			
20	24	11	F	Yates Petro. Corp.	Sara AHA Com.	6		308'	
20	24	14	I	Yates Petro. Corp.	John AGU	5			

TOWN	RANGE	SEC	UNITLTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
20	24	21	A	Yates Petro. Corp.	Albert AJM	1		62'	
20	24	22	C	Yates Petro. Corp.	Carl TP	3			
20	24	24	D	Nearburg Prod. Co.	Mayer 24	2		174'	
20	24	25	E	Yates Petro. Corp.	Chandelle McKay Com.	4		185'	
20	24	25	L	Yates Petro. Corp.	Kiehn ALA	1		172'	
20	24	26	A	Yates Petro. Corp.	Conoco AKG FED.	4		171'	
20	24	36	M	Marathon Oil Co.	Indian Hills St.	8		86'	
20	24	36	K	Marathon Oil Co.	Indian Hills St.	1		45'	
20	28	8	O	Chi Oper. Inc.	Savage	1			No salt section 960-1000 No capitan reef sec. 8
20	28	30	F	Exxon Corp.	Avalon Delaware UT	222			
20	28	32	E	EXXON CORP.	AVALON DELAWARE UT.	2220			
20	28	32	L	Exxon Corp.	Avalon Dela. Ut.	2420		1700'	
21	22	32	O	Premier Oper. Co.	Fanning Draw St.	1		Air Dr	Water 1390'-1490' hole full of water,fluid level 30'
21	23	2	J	Marathon Oil Co.	N. Indian Basin Ut.	10		Airdrl	
21	23	2	M	Marathon Oil Co.	N. Indian Basin Ut.	12		Airdrl	Fresh Water @ 218', Brackish Water @ 710'
21	23	2	O	Marathon Oil Co.	N.Indian Basin Ut	11		900	
21	23	16	A	Marathon Oil Co.	North Indian Basin Ut.	8		148	
21	24	36	M	Mitchell Energy Corp.	Indian Hills 36	1		117'	
21	26	9	E	Chi Oper. Inc.	Wiser St.	3		420	
21	26	9	F	Chi Oper. Inc.	OXY St.	2		1148	
21	26	9	K	Chi Oper. Inc.	OXY St.	1		650	B. Capitan-2130
21	26	9	N	Chi Oper. Inc.	Wiser Com.	5		448	
21	26	16	F	Devon Energy Corp.	Cactus State	9			
21	26	16	I	Devon Energy Corp.	Cactus State	10		1270'	
21	26	16	O	Devon Energy Corp.	Cactus St.	8			
21	26	16	O	Devon Energy Corp.	Cactus State	5			
21	26	18	A	Devon Energy Corp.	Cactus St.	12		770'	
21	26	18	B	Devon Energy Corp.	Cactus State	7		690'	
21	26	16	C	Devon Energy Corp.	Cactus St.	1		650	
21	26	18	D	Devon Energy Corp.	Cactus State	5			
21	26	16	E	Devon Energy Corp.	Cactus State	8			
21	26	16	G	Devon Energy Corp.	Cactus St.	3		78'	
21	26	18	G	Devon Energy Corp.	Cactus ST.	3		443'	LC-78'
21	26	18	J	Devon Energy Corp.	Cactus State	6			
21	26	16	K	Devon Energy Corp.	Cactus St.	4			
21	27	9	D	Ray Westall	Myrtle Myra	5			Capitan Reef 1248-1719
21	27	18	A	Ray Westall	Myrtle Myra	8			
21	27	17	F	Yates Petro. Corp.	Gilder AG St.	1		1264	
21	28	3	K	Energex Oil Co.	Teodoro St.	1			Capitan Reef 1360 2106
21	28	3	M	Pogo Prod. Co.	State	1		1359	
21	31	36	P	Pogo Prod. Co.	State 2	1			
21	31	36	P	Pogo Prod. Co.	State 2	1			
22	29	3	M	Oryx Energy Corp.	Conoco St. Gas Com.	2		542'	

TOWN	RANGE	SEC	UNITLTR	OPERATOR	PROP NAME	WELL NUM	WTR FLOW	LOST CIR	FRM TOPS
22	23	16	O	Chevron USA Inc.	Eagle Flats UT	16			
22	23	21	G	Yates Petro. Corp.	Wagon Ut.	1		835'	
22	24	2	K	Nearburg Prod. Co.	Big Walt 2 St.	3			
22	28	32	A	Louis Dreyfus Nat. Gas	E.V. State	1			
22	30	34	A	Exxon Oil & Gas Co.	James Ranch Ut.	71			Base Salt 3588'
22	30	36	K	Bass Enterprises Prod. Co.	James Ranch Unit	29			Base Salt - 3808'
22	30	36	N	BASS ENTERPRISES Prod. Co.	James Ranch Ut.	41			Base Salt 3664'
22	31	1	A	Yates Petro. Corp.	Graham AKB St.	1			B. salt 4073'
22	31	2	H	Yates Petro. Corp.	Graham AKB St.	2			
22	31	2	I	Pogo Prod. Co.	State 2	3			Base Salt 4100'
22	31	2	J	Pogo Prod. Co.	State 2 #4	4			Base Rustler @ 700'. Top Salt @ 800'.
22	31	2	K	Yates Petro. Corp.	Flora AKF State	2			Base Salt 4020'
22	31	2	N	Yates Petro. Corp.	Flora AKF St.	1	2032' flowed 25-30 bbl/hr w/H2S Svs.		
22	31	2	O	Pogo Prod. Co.	State 2	2	120BPH @ 3087' flowed to 0 10 Hrs.		
23	28	24	A	B.K. Oper. Corp.	Remuda Basin St.	2			Base Salt 3001'.
23	30	19	C	Texaco Expl. & Prod. Inc.	Remuda Basin 19 Fee	1			Base Salt 3328'
23	31	16	C	Yates Petro. Corp.	Medano VA St.	16			Base Salt 3912
23	31	32	E	Exxon Oil & Gas Co.	Poker Lake 32 St.	8			Base Salt 3840'
24	25	8	C	W.A. Moncrief Jr.	Jurnegan St.	1			
24	25	8	K	W.A. Moncrief Jr.	Jurnegan St.	2		1005'	Top Delaware-2784'
24	26	9	B	Santa Fe Energy	Mosley Canyon 9 St.	1		1070'	Base Capitan Reef 2484
24	26	10	C	HNG Oil Co.	S. Horseshoe Bend 10	1		1272'	
24	26	17	C	R.E. Hubbert	Ridge St	1		838'	
24	26	17	D	Santa Fe Energy	Lambchop 17 St. Com.	1		1533	Base Capitan Reef 2279'
24	25	20	B	Santa Fe Energy	Lambchop 20 Fed Com.	1		2090	Top Capitan Reef 845', Base Capitan Reef 2385'