PERFORMANCE ASSESSMENT FOR A NUCLEAR WASTE REPOSITORY

- THE WIPP EXPERIENCE

L. Chaturvedi, J. B. Chapman,
R. H. Neill, J. K. Channell
Environmental Evaluation Group
State of New Mexico
P.O. Box 968
Santa Fe, NM 87503

ABSTRACT

Performance Assessment to show compliance with the standards for a nuclear waste repository requires thorough site characterization and understanding of potential pathways for a breach of the repository. Although the Waste Isolation Pilot Plant (WIPP) project will not be licensed by the Nuclear Regulatory Commission (NRC) under 10 CFR 60, it is subject to the Environmental Protection Agency "Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes" (40 CFR Part 191). NRC has incorporated 40 CFR 191 into 10 CFR 60 and requires the demonstration of compliance before construction of the high level waste (HLW) repositories can begin. The Environmental Evaluation Group (EEG) of the State of New Mexico has independently evaluated the WIPP project since 1978 and believes that compliance for WIPP should be demonstrated prior to emplacement of waste for disposal. The U. S. Department of Energy schedule calls for the arrival of waste at WIPP in late 1988. DOE considers WIPP to be a research and development facility for the first 5 years of operation, and believes that compliance with the EPA Standards need not be demonstrated until after the decision is made not to retrieve the waste. It appears that DOE's mission plan for the first HLW repository has not provided sufficient time to resolve the site characterization issues and complete the performance assessment for each of the three sites before submitting a license application to NRC.

INTRODUCTION

Performance Assessment refers to the assessment of compliance of a nuclear waste repository with the Environmental Protection Agency (EPA) "Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes" contained in the Code of Federal Regulations 40 CFR Part 191. The Waste Isolation Pilot Plant (WIPP), as a repository for defense transuranic (TRU) wastes, is subject to the EPA Standard. Indeed, 40 CFR Part 191 was written to specifically include Department of Energy facilities that are not regulated by the Nuclear Regulatory Commission (NRC). The congressional authorization of WIPP (P.L. 96-164, 1979) confined the mission to defense wastes not regulated by the NRC. Therefore, while WIPP will be the first repository to which the EPA Standards will apply, it will not be licensed by the NRC.

WIPP will include experimental storage of 17 million curies of defense high level waste (HLW) in addition to the disposal of TRU wastes generated by the nation's defense program. According to the DOE's schedule, the TRU waste will start arriving at WIPP in October 1988. The repository is located in southeastern New Mexico at a depth of 855 meters in the lower part of a 600 meter thick salt formation known as the Salado Formation (Fig. 1). The presently planned size of the repository is about 50 hectares, located within an 800 hectare area which has been reserved for future expansion.

The Environmental Evaluation Group (EEG) was established by the State of New Mexico in 1978 to independently review all health and safety aspects of the WIPP project. The group consists of a multi-disciplinary staff of scientists and engineers who have closely evaluated the WIPP project for the past eight years. The evaluation has often resulted in recommendations for changes in the plans or for additional studies to resolve questions of the long and short term safety of the project. EEG will evaluate the effort to show compliance with the EPA Standard and will perform its own assessments to catch any major flaws in the DOE effort.

SITE CHARACTERIZATION

Knowledge of the geological and geohydrological characteristics of the site is essential for performance assessment. Site characterization work for the WIPP site began in 1974 and a borehole (ERDA-9) at the center of the present site was drilled in 1976. During the next two years (1976-78), 43 more holes were drilled to support the site characterization for WIPP. In 1978, the Sandia National Laboratories published a 2 volume Geological Characterization Report (1) which stated, "sufficient information has now been developed to allow the site to be adequately characterized for site selection purposes." (Pps. 2-7.) The EEG extensively commented on this report (2) and the Environmental Impact Statement for WIPP which was published in 1979. Between 1979 and 1983, EEG organized geotechnical meetings and field trips to try to identify and resolve specific site characterization issues and published analyses of breach scenarios (3 to 16). In a 1981 agreement between DOE and the State of New Mexico, DOE agreed to conduct additional geotechnical studies, which resulted in eleven "topical reports" on specific site characterization issues. These were published during 1982-83.

The DOE declared in 1983 that the site had been characterized and began full construction of the repository. The EEG evaluated the results of the site characterization activities completed at that time and concluded (17) that while the site had been sufficiently characterized to warrant confidence in its suitability for TRU waste disposal, additional work needed to be done to address uncertainties about shallow aquifer hydrology and the extent of deep seated pressurized brine. These additional studies are now underway and are expected to be completed by 1988. EEG has published the results of more independent studies since 1983 (19 to 23), which will be useful in the performance assessment. A detailed history of WIPP site characterization was presented at the Waste Management '86 Symposium (18).

COMPLIANCE WITH THE EPA STANDARD

The EPA Standard (40 CFR Part 191) was promulgated in November, 1985. The DOE has awarded contracts to both Westinghouse and the Sandia National Laboratories (SNL) to conduct the Performance Assessment for WIPP. Even though most of the site characterization work at WIPP will be completed by early 1988, the estimated date for the completion of studies to demonstrate compliance with the EPA Standard will be approximately 1992. While it is essential to conduct a thorough Performance Assessment, the present schedule for WIPP will result in the demonstration of EPA Standard compliance about 4 years after the waste emplacement begins at WIPP. This schedule also points out that the site characterization and performance assessment schedule for the first HLW repository is too optimistic.

The EPA Standard (40 CFR Part 191) contains two subparts. Subpart A relates to the environmental standards for management and storage of radioactive waste and applies to facilities designed for temporary retention of the waste that have the intent and capability to readily retrieve such waste. It also applies to the activities associated with emplacing waste for permanent disposal by requiring that the discharges of radioactive material and direct radiation from management and storage activities be limited so that any member of the public in the general environment should not receive a combined annual dose equivalent exceeding 25 millirems to the whole body, 75 millirems to the thyroid and 25 millirems to any other critical organ. Interestingly, for non-NRC regulated facilities such as WIPP, the Standard is somewhat less stringent and puts the limit at 25 millirems to the whole body and 75 millirems to any critical organ. The subpart A requirements to provide "reasonable assurance" to contain the releases can be satisfied by calculating expected performance of the storage system, combined with environmental monitoring to verify that any releases are within regulatory limits. System performance calculations will evaluate packaging, handling and storage, including the assurance of package integrity during the management and storage period, and the probability of accidents and fire which may breach the package. Subpart A applies to WIPP for the operations after receipt of waste until the time it is emplaced in an underground "room".

Subpart B of the Standard applies to disposal of radioactive waste, meaning permanent isolation "with no intent of recovery, whether or not such isolation permits the recovery of such fuel or waste (40 CFR 191.02e). Even though the waste will be emplaced at

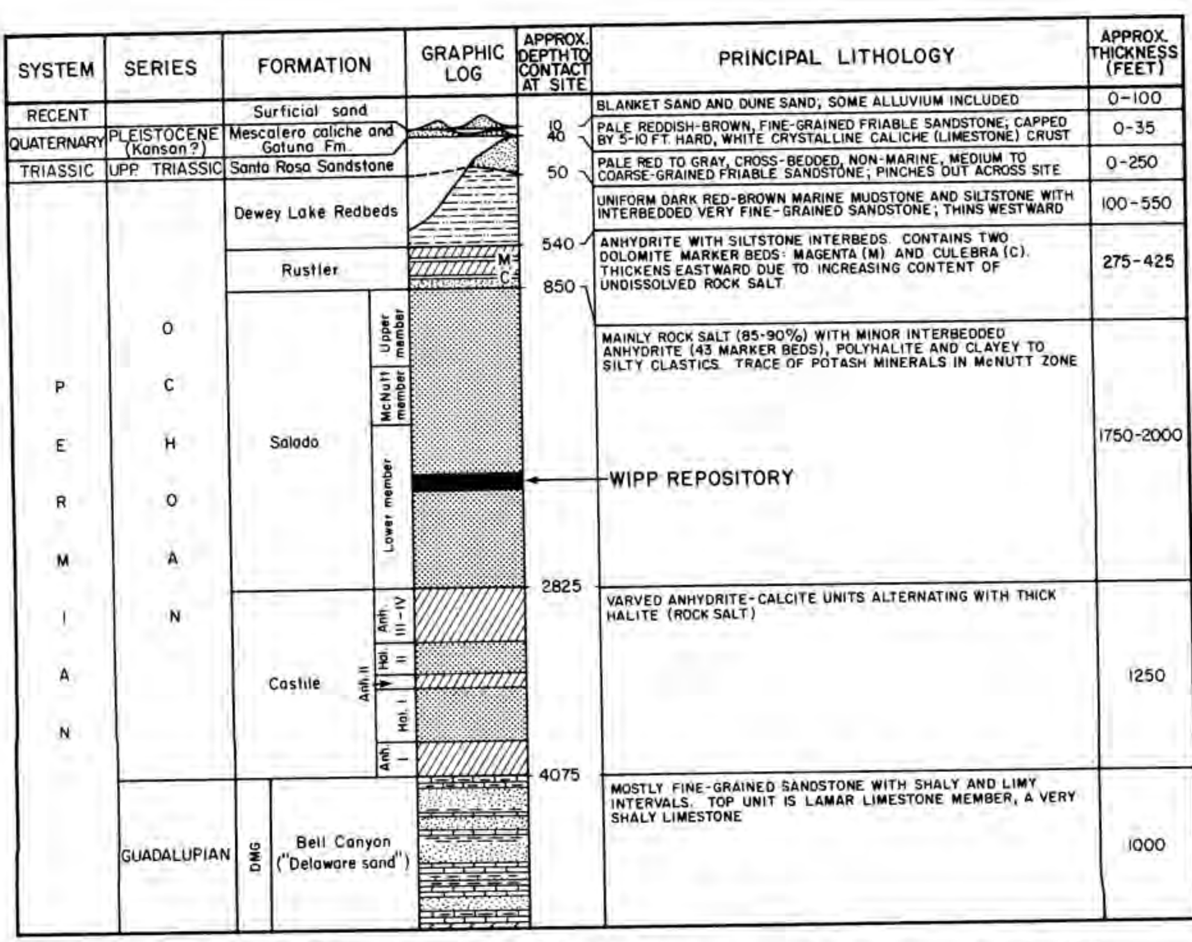

Fig. 1. Generalized Stratigraphy at the WIPP site. Adapted from Powers, et al. (1).

WIPP in a retrievable mode for the first five years of operations, there is no intent to recover it and therefore the provisions of subpart B of the Standard apply to WIPP beginning with waste emplacement. Since this is scheduled to occur in 1988, the WIPP repository will not have demonstrated compliance with the EPA Standard at the time disposal of the waste begins.

Subpart B of the Standard contains four "requirements", viz., Containment requirements, Assurance requirements, Individual Protection requirements and Groundwater Protection requirements.

Containment Requirements

The Containment requirements are based on probabilities of cumulative releases of different radionuclides to the accessible environment for 10,000 years after disposal. This requirement relies heavily on probabilities and allows small amounts of radioactive releases at higher probabilities and larger amounts at lower probabilities. Performance assessment to meet this requirement will consist of the following steps. All aspects of a waste disposal system should first be evaluated. These include the waste type, form and radionuclide content; physical and chemical durability of the containers and overpack, if any; physical and chemical properties of the backfill; expected integrity of the plugs and seals; characterization of the geologic system including rock types, fractures, water, discontinuities, etc.; and the geohydrologic system of potential pathways of contaminant transportation after a breach. Once the site has been carefully characterized and various components of a possible breach path are well understood, scenarios for breach of the repository can be developed. Many of the scenarios will involve a combination of human and natural events, since, according to the Standard, the knowledge of the repository cannot be assumed for more than 100 years after closure.

Once a large number of scenarios have been developed, they should be screened according to the probabilities of the events and processes constituting them and only those with a probability of one chance in 10,000 of occurring in 10,000 years need to be evaluated for consequence modeling. If the results of the most probable or most severe scenarios do not satisfy the Containment requirement, there would be no need to perform detailed consequence analysis of the less probable or less severe scenarios. If they do satisfy the requirement, then the less probable/less severe scenarios should be analyzed to assess if the site meets the requirement.

The consequence analysis consists of analyzing the release of radionuclides to the accessible environment on the basis of a selected scenario. Rational assumptions based on the most accurate and up-to-date information should be made for the breach of the waste package, movement out of the repository and transportation through an aquifer or directly to the surface. Factors such as the source-term, waste-form solubility and corrosion, retardation by backfill, performance of plugs and seals, decay of radionuclides and their daughters, groundwater flow and the movement of radionuclides by groundwater, retardation of radionuclides by the host rock, etc. will have to be considered for consequence analysis.

Since the consequence analysis will be based on predictions for the next 10,000 years, there are many sources of uncertainty in the predictive model. For each scenario and consequence model, an uncertainty analysis should therefore be performed to identify the controlling parameters of an analysis and to quantify the uncertainty in the results of the model caused by uncertainty in these parameters.

Scenario analysis and consequence modeling have been performed for WIPP in the past. The results of these analyses can be found in several EEG reports (2, 5, 6, 7, 8, 9, 10, 11, 22), as well as in the Final Environmental Impact Statement and Safety Analysis Report for WIPP. Spiegler (6) evaluated a scenario in which brine from the Castile Formation leaches radioactivity from the repository and enters a water bearing zone in the overlying Rustler Formation (Fig. 1). The health risks posed to individuals using water from a well completed in the Rustler 5 km down gradient of the site were determined to be insignificant, assuming that adsorption retards a major fraction of the plutonium.

The consequences of a connection between the repository and the surface via a borehole intercepting pressurized brine below the repository were found to be possibly significant by Channell (8). Channell's analysis included estimating probabilities of occurrence for the events constituting the scenario.

Scenarios involving natural resource exploitation (such as solution mining of halite) were examined by Little (9). The consequences of these scenarios were found to either be bounded by hydrologic transport in the Rustler Formation, or to result in insignificant health effects from consumption of contaminated salt.

The Performance Assessment analysis will reexamine the above scenarios and many others. However, this new effort will not be "re-inventing the wheel" for WIPP. All possible release scenarios involving WIPP depend on the geologic and hydrologic characterization of the WIPP area. Within the last few years, the conceptualization of the hydrologic regime around WIPP has changed significantly and will continue to change as the results of ongoing hydrologic tests become available. Recent testing has revealed that the Culebra Dolomite (the most transmissive water-bearing unit in the Rustler Formation) contains highly permeable fractures and possibly karst conduits. Incorporating the presence of karst channels in a hydrologic release scenario at WIPP was found by Chaturvedi and Channell (22) to drastically increase the severity of a repository breach. Not only would the presence of fractures and karst conduits increase water velocity, the reduced rock surface area that contaminated water would contact also reduces adsorption of nuclides. In addition, the ongoing geophysical testing, recommended by EEG, may indicate whether a pressurized brine reservoir in the Castile Formation underlying the repository is present.

Determining compliance with the EPA Standard will provide an opportunity to incorporate the maturing conception of Rustler hydrology into WIPP release scenarios. In addition, rather than postulating health effects from ingestion of water at either a ranch well or Malaga Bend on the Pecos River, the Standard sets a definite boundary, no more than 100 square kilometers in area or 5 km in any direction from the boundary of the wastes, where release limits must be met. Probabilities will need to be calculated for the first time for most scenarios and source terms and radionuclide behavior need to be reevaluated using updated waste inventories and geochemical data.

Assurance Requirements

The Assurance requirements are included in the Standard to provide the confidence needed for long-term compliance with the Containment requirements.

For facilities to be licensed by the NRC, these requirements do not apply but comparable regulations are contained in the Siting Criteria of the NRC regulations (10 CFR Part 60.122). WIPP will therefore be the first and perhaps the only repository to which EPA's Assurance requirements will apply. These requirements consist of active institutional controls such as permanent markers, records, etc.; use of both engineered and natural barriers in the design; and avoidance of sites with reasonable expectation of future exploration for scarce or easily accessible resources unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

Before the EPA Standards were issued, DOE had decided to postpone making decisions on the questions of active and passive institutional controls and monitoring after disposal until one year before decommissioning of the repository. Compliance with the Standards, however, includes development of plans for post decommissioning controls and monitoring. Similarly, DOE has not yet made a commitment on the use of engineered barriers in the WIPP design. The containers for the contact-handled transuranic (CH-TRU) waste will be conventional DOT-17C 55 gallon steel drums which are not expected to last beyond a few tens of years in the corrosive salt environment. No decisions on the use of getters in the backfill have been made although research is in progress on the physical and chemical properties of various mixtures of bentonite clay and crushed salt. The requirement for avoiding mineral resources in selecting a disposal site cannot be met by WIPP without the provision contained in the Standard, "unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future." (10 CFR 191.14f). There are potash deposits including the scarce mineral Langbeinite in the McNutt Potash zone (Fig. 1) of the Salado Formation 200 meters above the repository and there are natural gas (and possibly oil) accumulations several thousand meters below the repository. As a part of demonstrating compliance with the Standards, it will have to be shown that the favorable characteristics of the WIPP site compensate for a greater likelihood of the site being disturbed in the future.

Individual Protection Requirements

The Individual Protection Requirements relate to the "undisturbed performance" (predicted behavior without human intrusion or unlikely natural events) of a repository for 1000 years after disposal and require that the annual dose equivalent to any member of the public in the accessible environment should not exceed 25 millirems to the whole body or 75 millirems to any critical organ. Scenario development and consequence analyses will have to be performed to show compliance with this requirement, similar to those needed for the containment requirements, with the addition of assumptions related to the mechanism of ingestion by people in order to calculate individual doses.

Previous work by both EEG and DOE has not quantitatively evaluated the undisturbed repository performance because both the likelihood and severity of undisturbed releases was considered to be small. The Individual Protection Requirements have generated new attention as the result of brine inflow studies conducted by Nowak (24) in the WIPP repository. These studies have shown that a much higher than anticipated rate of brine inflow occurs toward the heaters. Pressurization of boreholes open in the Salado has also been observed (25). This has led to concerns about a rapidly flooded repository (possibly saturated in as little as a few hundred years) once the shafts are sealed and ventilation stops (J. Bredehoeft, pers. comm., 1986). A fluid-filled repository will become pressurized by both creep closure of the halite and gas generation by the waste. This pressurization could provide a driving force for radionuclide-saturated fluid to move out to the environment along shaft or borehole seals. The analysis of WIPP's undisturbed performance will probably be focused along this evaluation of seal integrity in contact with pressurized repository fluids.

Groundwater Protection Requirements

The Groundwater Protection Requirements relate to the undisturbed performance of the repository for 1000 years after disposal such that the usable groundwater resources are not polluted. Compliance with this requirement requires scenario development and consequence analyses to determine radionuclide concentrations in any "special source of groundwater" affected by the repository. No special sources of groundwater exist in the WIPP area that satisfy the EPA definition, so this requirement does not apply to WIPP.

TIME REQUIREMENT FOR PERFORMANCE ASSESSMENT

Although a formal program of Performance Assessment of WIPP began after the EPA Standards were issued in 1985, a large amount of geohydrologic work and analyses of breach scenarios had been conducted between 1974 and 1985. In spite of over 10 years of field and analytical work, however, sufficient data on subsurface hydrology of the WIPP site still does not exist to conduct a satisfactory performance assessment. DOE's position is that the WIPP will be a research and development facility for the first 5 years of operation and compliance with the EPA Standards need not be demonstrated until the facility is about to become a "repository" i.e. after the decision is made to not retrieve the emplaced waste. The EEG position is that the compliance should be demonstrated before emplacing waste for disposal at WIPP. While the WIPP project is exempt from licensing by the Nuclear Regulatory Commission (NRC), the DOE will have to show compliance with the EPA Standards before the NRC issues a license to begin construction of a high level waste repository.

Performance Assessment is a long and complicated process and requires geological assessment, subsurface studies through geophysical methods and drilling, hydrologic testing and modeling, assessment of probabilities of potential breach scenarios and calculation of quantities of radionuclides released to the accessible environment. The WIPP experience indicates that sufficient time may not have been allowed to carry out performance assessment for high level waste repository sites.

REFERENCES

1. D. W. POWERS, S. J. LAMBERT, S. E. SHAFFER, L. R. HILL and W. D. WEART (editors), "Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico", SAND78-1596, Sandia National Laboratories, 2 Vol. (1978).

2. R. H. NEILL, J. K. CHANNELL, C. WOFSY, M. A. GREENFIELD (editors), "Radiological Health Review of the Draft Environmental Impact Statement, Waste Isolation Pilot Plant", EEG-3, Environmental Evaluation Group (1979).

3. ENVIRONMENTAL EVALUATION GROUP, "Geotechnical Considerations for Radiological Hazard Assessment of WIPP, A Report of a Meeting Held on January 17-18, 1980", EEG-6, Environmental Evaluation Group (1980).

4. L. CHATURVEDI, "WIPP Site and Vicinity Geological Field Trip", EEG-7, Environmental Evaluation Group (1980).

5. C. WOFSY, "The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP", EEG-8, Environmental Evaluation Group (1980).

6. P. SPIEGLER, "An Approach to Calculating Upper Bounds on Maximum Individual Doses from the Use of Contaminated Well Water Following a WIPP Repository Breach", EEG-9, Environmental Evaluation Group (1981).

7. ENVIRONMENTAL EVALUATION GROUP, "Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy", EEG-10, Environmental Evaluation Group (1981).

8. J. K. CHANNELL, "Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine", EEG-11, Environmental Evaluation Group (1982).

9. M. S. LITTLE, "Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP", EEG-12, Environmental Evaluation Group (1982).

10. P. SPIEGLER, "Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository", EEG-13, Environmental Evaluation Group (1982).

11. S. T. BARD, "Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon", EEG-15, Environmental Evaluation Group (1982).

12. ENVIRONMENTAL EVALUATION GROUP, "Radionnuclide Release, Transport and Consequence Modeling for WIPP, A Report of a Workshop Held on September 16, 17, 19", EEG-16, Environmental Evaluation Group (1982).

13. P. SPIEGLER, "Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site", EEG-17, Environmental Evaluation Group (1982).

14. P. SPIEGLER, "Origin of the Brines Near WIPP From the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen", EEG-18, Environmental Evaluation Group (1983).

15. S. FAITH, P. SPIEGLER, and K. R. REHFELDT, "The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site", EEG-21, Environmental Evaluation Group (1983).

16. ENVIRONMENTAL EVALUATION GROUP, "EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983", EEG-22, Environmental Evaluation Group (1983).

17. R. H. NEILL, J. K. CHANNELL, L. CHATURVEDI, M. S. LITTLE, K. REHFELDT, and P. SPIEGLER, "Evaluation of the Suitability of the WIPP Site", EEG-23, Environmental Evaluation Group (1983).

18. L. CHATURVEDI, "Site Characterization for High Level Nuclear Waste Repositories - Lessons to be Learned From WIPP", Waste Management '86, Proc. Symp. on Waste Management, Tucson, Arizona, March 1986, Vol. 2, p. 107 (1986).

19. L. CHATURVEDI, "Occurrence of Gases in the Salado Formation", EEG-25, Environmental Evaluation Group (1984).

20. K. REHFELDT, "Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite", EEG-27, Environmental Evaluation Group (1984).

21. D. RAMEY, "Chemistry of Rustler Fluids", EEG-31, Environmental Evaluation Group (1985).

22. L. CHATURVEDI and J. CHANNELL, "The Rustler Formation as a Transport Medium for Contaminated Groundwater", EEG-32, Environmental Evaluation Group (1985).

23. J. CHAPMAN, "Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area", EEG-35, Environmental Evaluation Group (1986).

24. E. J. NOWAK, "Preliminary Results of Brine Migration Studies in the Waste Isolation Pilot Plant (WIPP)", SAND86-0720, Sandia National Laboratories (1986).

25. J. W. MERCER, "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, Sandia National Laboratories (1987).