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STATE OF NEW MEXICO

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M E M O R A N D U M

DATE: February 10, 1988

TO: Governor Garrey Carruthers

THRU: Larry Gordon, Secretary HED

THRU: Michael Burkhart, Director EID

FROM: Robert H. Neill, Director EEG

SUBJECT: Weekly News Item

The following is intended to keep you posted in the states of the evaluation of post-closure brine seepage at the WIPP Site.

EEG is scheduled to meet with Sandia on February 11, 1988 to review their recent analyses (agenda attached).

The NAS Panel is scheduled to review the materials developed by Sandia, EEG, and others at a meeting on February 18 and 19.

A paper by Dr. Lokesh Chaturvedi, Dr. James K. Channell, and Ms. Jenny B. Chapman is enclosed as background information. We will keep you posted as information develops.

RHN:cc

Enclosures

Copy to RHN + JBC

BRINE INFLOW MEETING
DOE/WPO-EEG-SNL

Purpose: To present and discuss 1) the current data and analysis details of brine inflow to WIPP disposal rooms, and 2). the implications for safe disposal of TRU waste in WIPP.

Date: Feb 11, 1988

Time: 8:30am to 3:00pm

Location: Building 825 Conference Room
Sandia National Labs
Kirtland AFB
Albuquerque, NM

AGENDA FOR BRINE INFLOW MEETING

Opening Remarks	T. Lukow DOE	8:30- 8:35
Introduction	L. Tyler SNL	8:35- 8:45
Data Presentation		
Underground Observations	D. Deal W/IT	8:45- 9:15
Inflow Experiments	J. Nowak SNL	9:15- 9:45
Inflow Data Analysis	D. McTigue SNL	9:45-10:15
Break		10:15-10:30
Analytical Modeling	D. McTigue SNL	10:30-10:45
Panel Model Analysis	R. Beraun SNL	10:45-11:15
Backfill Absorption Analysis	J. Nowak/B. Butcher	11:15-11:45
Lunch		11:45- 1:00
Room Closure Analysis	D. Munson SNL	1:00- 1:30
Room Performance	L. Tyler SNL	1:30- 2:00
P. A. Implications	R. Anderson SNL	2:00- 2:45
Summary	T. Lukow DOE	2:45- 3:00

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POTENTIAL PROBLEMS RESULTING FROM THE PLANS FOR THE FIRST FIVE YEARS OF THE WIPP PROJECT

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is scheduled to start receiving defense transuranic (TRU) wastes in October, 1988. The U. S. Department of Energy (DOE) has planned to store up to 126,000 drums of contact-handled (CH-TRU) waste without backfill during the first five-year period. This waste will have to be removed and restacked with backfill during the next 10 years while new waste will be arriving for disposal. To make matters more complicated, it appears that the existing drums of CH-TRU waste have too much void space and since the drums are expected to become corroded in a few tens of years, the brine issuing from the salt walls may form a slurry of waste in a few hundred years after closure. Preliminary calculations indicate that such conditions may violate the EPA Standards (40 CFR 191.13) on the basis of analyses of human intrusion scenarios. DOE does not plan to complete the performance assessment work to assess WIPP's compliance with the EPA Standards until 1993. If the waste drums and boxes have to be reprocessed to reduce void space in them and the backfill is redesigned to include cement or chemical grout mixtures instead of the presently planned salt/bentonite mixture, each drum may have to be brought up to the surface for reprocessing and taken down again for final disposal. It would be simpler and less hazardous to emplace substantial quantities of waste underground only after the decisions about any needed reprocessing of the waste drums and the design of backfill have been finalized.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a repository for the disposal of transuranic (TRU) wastes resulting from defense activities of the U.S. Government. The Public Law (P.L. 96-164, 1979) authorizing WIPP exempted it from licensing by the Nuclear Regulatory Commission (NRC). The repository has been designed to dispose 156,000 cubic meters (5.5 million cu. ft.) of contact-handled transuranic (CH-TRU) waste and 4250 cubic meters (150,000 cu. ft.) of remote-handled transuranic (RH-TRU) waste. In addition, the U. S. Department of Energy (DOE) plans to emplace 28 cubic meters (1000 cu. ft.) of defense high-level waste (HLW) for experiments. The HLW will be retrieved before decommissioning the repository. DOE plans to start shipping the TRU waste to WIPP in October, 1988 and has designated the first five-year period of operations as the Research and Development (R&D) phase. While an NRC license is not required for WIPP, the facility must comply with the "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" promulgated by the Environmental Protection Agency (EPA) and contained in 40 CFR 191.

In the absence of NRC regulatory authority over WIPP, the State of New Mexico's Environmental Evaluation Group (EEG) provides the only full-time technical review and oversight of the WIPP project. The EEG consists of a group of eight scientists representing the disciplines of geology, hydrology, health physics, environmental engineering, and environmental monitoring, and has been in existence since 1978 with funds provided by DOE to the State of New Mexico. The evaluation by this group has resulted in several recommendations for changes in the plans or for additional studies to resolve questions of the long- and short-term safety of the project. These recommendations have generally been accepted by DOE.

While DOE has designated the WIPP Project as a R&D facility for the first five years (1988-93) of operations, the R&D plans that would require waste to be emplaced underground have not yet been published. Nevertheless, DOE plans to emplace up to 126,000 drums of CH-TRU waste underground in an easy retrieval mode for the first five-year period. It now appears that this temporarily stored waste will not just have to be removed for proper emplacement with backfill, it may have to be reprocessed before re-emplacement for disposal in order to be in compliance with the EPA Standards.

The WIPP repository is located in southeastern New Mexico, 40 km east of Carlsbad, New Mexico (Fig. 1) at a depth of 855 meters in the lower part of a 600-meter thick salt formation known as the Salado Formation (Fig. 2). The presently planned size of the repository is about 50 hectares, located within an 800 hectare area that has been reserved for future expansion. The repository will consist of 8 "panels" with 7 "rooms" (300 ft x 33 ft x 13 ft) in each panel (Fig. 3). CH-TRU waste will be emplaced in 55-gallon drums stacked 3 high in the rooms and in the drifts connecting the rooms and in boxes. RH-TRU waste will be disposed in 36-inch diameter horizontal holes in the walls of most of the rooms. Three vertical shafts, the experimental areas north of the shafts, access drifts to the repository including one drift (E140) to the southern edge of the repository, and two rooms in Panel 1 (northeast panel) have been excavated. Before decommissioning in the year 2006, each panel entry through the two east-west drifts will be plugged and sealed. Entry to each room is not planned to be sealed since the approach drifts will also be used for disposing the CH-TRU waste.

RETRIEVABILITY AND BACKFILL

The concept of maintaining easy retrievability for the WIPP waste for five years after first emplacement has been a part of the WIPP design since 1980 (1). Since the retrieval of waste emplaced for the first five years would require 5 to 10 years after the decision to retrieve is made, prediction of "room" conditions for up to 15 years after excavation is needed. Before underground excavation at WIPP, the predicted rate of room closure was such that a 13-ft. high and 33-ft. wide room would not undergo sufficient plastic deformation to threaten crushing and breaching of the drums for at least 15 years. Salt deformation rates measured in the WIPP excavations were, however, found to be 3 to 5 times larger than the computed values (2). In spite of detailed investigations of the halite parameters, the reason for this discrepancy remains unresolved (3). Figure 4 shows the large difference between the predicted and the measured roof-to-floor closure of test rooms 1, 2, 3, and 4 (see Fig. 3 for location of these rooms northwest of the shafts). The test rooms were excavated to be the same dimensions as the actual repository rooms. The observed higher rates of salt creep would not allow easy retrievability of 5 years of waste and a careful analysis of the situation in 1986 resulted in 5 design modification options (4) as follows:

1. Reduce the volume of waste to be stored; retain backfill and retrieve within 7 years of excavation.

2. Use no backfill, retain the original volume of waste, but retrieve within 7 years of excavation.

3. Excavate the rooms to 14 x 34 feet and trim again to that dimension after one year. Complete retrieval within 6 years of initial excavation. Allow crushing and breaching of the CH waste containers before retrieval if backfill is emplaced.

4. Reduce creep rate by reducing the room width from 33 ft to 28 ft. This would require reducing the pillar width between the rooms from 100 ft to 84 ft to accommodate the same volume of rooms within the repository area. Emplacement of backfill would be allowed under this option. This alternative would require additional engineering evaluations.

5. Make no changes in the planned room dimensions, waste volume, and backfill requirement, but allow crushing and breaching of the waste drums prior to their retrieval.

The analyses presented in the Design Validation Final Report (4) made it clear that unless the facility is to be completely redesigned in view of the observed higher rate of salt creep, it would not be possible to retrieve the waste emplaced during the first five years without the drums getting crushed and breached before retrieval. Since the backfill would transfer the load from the ceiling and walls to the waste drums, stacking the drums in the rooms without backfill would resolve the immediate problem of how to maintain 5 year retrievability. DOE therefore made a decision to defer emplacement of backfill until after 5 years of WIPP waste emplacement operations. Up to 126,000 drums of CH-TRU waste are thus planned to be stacked without backfill in three panels of WIPP during the first five-year period.

For permanent isolation of nuclear waste, emplacement of properly designed backfill around and over the drums is essential. Backfill is the only engineered barrier in the WIPP design and is required by the EPA Standards, the Design Criteria for WIPP, and the Consultation and Cooperation Agreement between DOE and the State of New Mexico. Within the rooms and drifts filled with waste, the backfill would completely occupy the empty space between the drums, the drums and the walls, and the top of the drums and the ceiling. To be most effective, and in order to not leave empty spaces, the backfill should be emplaced after stacking each row of 7-pack drums along the width of a room or drift.

After 5 years, a waste room 300 ft long, 33 ft wide, and 13 ft high would be filled with 6000 drums of CH-TRU waste stacked 3 drums high. The distance between the ceiling and the top of the drums would be barely 2 feet. To attempt to emplace backfill from the end of a 300 ft long room by "pneumatic stowing" may not accomplish the desired goal. Therefore, up to 125,000 drums of CH-TRU waste will have to be removed from the rooms for re-emplacement with backfill. Since the process of removing the nuclear waste drums is elaborate and slow, it is expected to take up to twice as long as emplacement. So for 10 years after the first five-year period, i.e., between the years 1993 and 2003, the WIPP Project will have the task of removing and re-emplacing the CH-TRU drums because the waste will not have been properly emplaced with backfill from the start. Continuous arrival of new waste during this period will make the operations very complicated.

The analyses to judge WIPP's compliance with the EPA Standards 40 CFR 191 are being conducted by a performance assessment team of scientists at the Sandia National Laboratories (SNL). While these analyses will not be completed until 1993, preliminary results show that some reprocessing of waste and redesign of backfill may be required to meet the EPA Standards. To accomplish that, the stored 126,000 drums of CH-TRU waste will not only have to be removed and restacked underground, they may have to be brought to the surface for reprocessing before restacking underground with a designed backfill. The possibility of the repository becoming saturated with brine in a few hundred years after closure has indicated the need for reprocessing the waste and redesigning the backfill. This issue is discussed in more detail in the following sections.

POST-CLOSURE REPOSITORY CONDITIONS: BRINE INFLOW AND GAS GENERATION

Unlike the conceptual designs for a HLW repository, the WIPP design does not include a multi-barrier system concept. The 55-gallon drums will be certified to last for only 20 years and the waste is not fixed in an insoluble matrix. Until 1987, DOE was not willing to commit to include a backfill in the WIPP repository design. The WIPP repository rooms were postulated to close around the waste due to salt creep and entomb the waste drums in 100 to 200 years. Observations in the WIPP excavations since 1983, however, indicate that the salt at the WIPP repository horizon is saturated with brine and the rooms and drifts will begin to fill with brine once the ventilation of the facility ceases to remove moisture (5). In addition, recent electro-magnetic surveys performed directly above the WIPP repository show that brine appears to be present 250 meters below portions of the WIPP repository in the upper part of the Castile Formation (6). Pressurized brine reservoirs in the Castile Formation have been encountered in at least 13 out of more than 60 boreholes drilled to that depth in the area around the WIPP site (7). The one encountered by the borehole WIPP-12 about 2.5 km north of the repository was estimated to contain 17 million barrels of pressurized brine.

The impact of the Salado Formation brine and the Castile Formation pressurized brine reservoirs, on the long-term integrity of the WIPP repository can be determined by analyzing the consequences of breach of the repository. Figure 5 shows some of the postulated breach scenarios based on someone drilling into or through the repository several hundred years after the knowledge of the repository is lost. The EPA Standards (40 CFR 191) do not permit credit to be taken for more than 100 years for maintaining the knowledge about the existence of a nuclear waste repository. Channell (8) and Bard (9) analyzed the consequences of human intrusion involving the Castile Formation brine reservoirs and concluded that the consequences would be acceptable. Much new information is now available, however, and these analyses will have to be updated.

This paper only discusses the consequences of breach of the repository by someone drilling directly into the repository and a slurry of waste and brine coming out to the surface. Consequences of drilling through the repository into the underlying brine reservoir and other scenarios will be analyzed in future publications.

Though anomalous quantities of brine in the WIPP excavations have been noted for several years, the long-term significance of brine inflow has only been appreciated recently. Bredehoeft (5) has shown that the excavations could provide sufficient brine to saturate the closing rooms of the repository in a few hundred years. The danger lies in the possible formation of a radioactive slurry that could be brought to the surface by inadvertent human intrusion. If the waste is in slurry form rather than consolidated into a solid mass by salt creep, enough radioactive material could be brought to the surface through drilling-fluid circulation to exceed the limits set by the EPA Standards, 40 CFR 191. In fact, calculations by SNL (10) show that between 5 and 15 m^3 (30 to 90 barrels) of "slurry" of brine and waste released to the surface will violate the EPA Standards.

More recent SNL calculations (11) discount the brine inflow problem by concluding that inflow will be low enough to be absorbed by backfill without the danger of slurry formation. However, these new calculations are based on non-conservative assumptions of parameters that are not well known. Three important factors in the calculation are formation permeability, formation porosity, and the length of time allowed for brine inflow.

Nowak (11) uses salt permeabilities of 10^{-9} to 10^{-8} darcies to calculate the quantity of brine inflow for 100 years after closure of the repository. These values were chosen because of their consistency with permeabilities calculated from brine inflow observations by Deal and Case (12) in boreholes drilled at the repository level. However, Deal and Case (12) concede that "Evaporation has played a significant role in reducing the measured amounts of brine inflow", a situation that would lead to erroneously low calculated permeabilities. Other SNL investigators have concluded that "for salt, maximum permeability is less than 1 microdarcy" (13) and that values of 10^{-8} to 10^{-6} darcy "are, in fact, representative of the permeabilities estimated for WIPP salt to date" (14). Permeabilities measured in the marker beds and clay seams located within 1.5 to 3 meters of the rooms (Fig. 6) are much higher, greater than 1 darcy in some cases (17). Given the range in observed values and uncertainties in assumptions used to calculate permeability, brine inflow calculations should consider a range in Salado Formation permeability of at least 10^{-9} to 10^{-6} darcies.

Assuming similar permeabilities, the Nowak (11) calculations result in inflow quantities an order of magnitude less than those in Bredehoeft (5) because of the porosity values used. Nowak (11) uses a salt porosity of 0.001, while Bredehoeft (5) uses 0.01. The calculation of permeability from various tests performed in the repository requires the assumption of a porosity value, but the calculations are not always particularly sensitive to the porosity value chosen (15, 16). Calculated Salado porosities range from 0.01 to 0.001 (13, 17). As with the permeabilities, at least this full range of repository porosity values should be used in calculating brine inflow.

Another critical unknown in determining the consequence of brine inflow is the period of time which the calculations consider. Nowak's (11) analysis assumed that "salt creep is expected to close these rooms within 100 years, preventing further accumulations of brine." However, room closure is not the controlling factor; brine flow is caused by the pressure gradient between the in situ brine and the open rooms and will continue as long as that gradient exists. Though the rooms may be effectively "closed" (floor and ceiling touching) within 100 years, the repository will be far from the conditions of undisturbed salt. Brine will continue to flow into the area around the waste until no pressure gradient exists between brine in the formation and brine in the excavated area. A question remains as to how much open pore space is needed to allow the waste to become entrained in a slurry. The brine inflow calculations should, therefore, be carried out past 100 years and in conjunction with repository closure models in order to adequately predict the state of the waste repository rooms.

Gas generation is another factor that may affect repository closure and brine inflow into a waste room. Gas can be generated during waste degradation by four means: 1) radiolysis, 2) thermal decomposition and dewatering, 3) chemical corrosion, and 4) bacterial action. Gas generation was a matter of concern when developing the Waste Acceptance Criteria (18) because of the possibility of fires and explosions during operations and pressurization and mine inflation after closure.

Assuming a gas-generation rate of 5 moles/drum/year, a salt permeability of $5x10^{-7}$ darcy delays creep closure until the gas producing material is exhausted in 400 years (18). In this case, the drifts do not completely close until the gas has diffused into the salt, 800 years after the repository is decommissioned. Calculations using a formation permeability of $5x10^{-7}$ darcy resulted in the mine pressure exceeding lithostatic pressure, "allowing the drift to remain open and even expand slightly" (18). The gas generation rate that will actually occur is very uncertain; 5 moles/drum/year may or may not be conservative.

The retardation of closure by gas generation could allow hundreds of more years of open void space in the repository. Brine inflow will slow and eventually cease if the pressure exceeds the hydraulic pressure of the brine in the adjoining formation. However, the time period of flow to consider could be much longer than the 100 years assumed by Nowak (11) and thus the brine inflow volumes could be greater. With the 10^{-9} to 10^{-8} darcy permeabilities assumed by Nowak (11) and a 5 mole/drum/year gas generation rate, the repository will remain open indefinitely due to gas pressurization. Though brine inflow may cease (and indeed could be reversed) as pressures build above lithostatic, a slurry situation could occur anyway if a drill hole penetrates the repository and drilling fluid entrains the uncompacted waste.

The research in support of the Waste Acceptance Criteria (18) used a value for in situ permeability of 10^{-5} darcy, based on measured in situ permeabilities. In an effort to be conservative, gas generation limits were brine in a few hundred years after closure. Since the CH-TRU waste containers are ordinary 55-gallon drums that will become corroded and breached within a few tens of years, the brine could form a slurry of waste in the repository rooms. Preliminary calculations indicate that this condition may result in violation of the EPA Standards (40 CFR 191.13). Recently published maximum estimates of brine inflow for the first 100 years of the repository do not appear to use conservative hydrologic parameters. There does appear to be a potential problem of long-term isolation of waste at WIPP under the existing design. Engineering solutions to prevent the problem include reprocessing of each drum to reduce the void space and inclusion of cement or chemical grouts in the backfill. Less expensive engineering solutions have not yet been identified, although it would perhaps be possible to include a mechanism for removal of brine from the repository level and provision of some absorbent material at a lower level.

If the 126,000 drums have to be reprocessed, they may have to be brought back to the surface and taken down again for final emplacement with properly designed backfill. It would be simpler and reduce radiation exposure at WIPP to emplace substantial quantities of waste underground only after the decisions about any needed reprocessing of the waste drums and the design of backfill have been finalized.

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POTENTIAL PROBLEMS RESULTING FROM THE PLANS
FOR THE FIRST FIVE YEARS OF THE WIPP PROJECT

List of figures for Chaturvedi, Channell, Chapman Paper

(To be typed below the figures after reduction.)

Fig. 1: Location of the WIPP site.

Fig. 2: Generalized geologic cross-section at the WIPP site.

Fig. 3: Underground layout of the WIPP repository and the experimental area.

Fig. 4: Roof-to-floor closure rate of the experimental rooms at WIPP.

Fig. 5: Postulated breach mechanisms of the WIPP repository.

Fig. 6: Clay and anhydrite layers immediately above and below the WIPP repository.

FACTS AND IMPLICATIONS OF A "WET REPOSITORY" SCENARIO FOR THE WASTE ISOLATION PILOT PLANT (WIPP)

by

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for the

New Mexico Radioactive Waste Consultation

Task Force Meeting

JANUARY 13, 1988

FACTS AND IMPLICATIONS OF A "WET REPOSITORY" SCENARIO FOR WIPP

by Lokesh Chaturvedi

Environmental Evaluation Group

INTRODUCTION

At a Congressional subcommittee* hearing on the Land Withdrawal Bill for the WIPP project, held on December 8, 1987 in Washington, DC, testimony was presented of the results of a study by a group of 11 New Mexico scientists (Scientists Review Panel on WIPP), entitled "Evaluation of the Waste Isolation Pilot Plant (WIPP) as a Water-Saturated Nuclear Waste Repository". Although a complete paper on the subject has not yet been published, we have received a draft copy of the paper from the Group. The testimony was reported on the front page of the New York Times (12/17/87), in the "News of the Week in Review" section of the Sunday New York Times (12/20/87), in Newsweek (12/28/87), as well as in most regional newspapers. The Albuquerque Journal of December 27, 1987 has an editorial on the subject. Dr. Wendell Weart of Sandia National Laboratory, the Scientific Advisor to DOE on the WIPP Project, is quoted in the Santa Fe New Mexican (12/20/87) that these concerns have been discussed with the Environmental Evaluation Group (EEG). The following is a summary of the information that EEG has on this subject. This paper discusses the implications of the Salado Formation brine only and does not address the failure scenarios connected with the pressurized brine in the underlying Castile Formation, or the overlying Rustler Formation aquifers.

THE ISSUE

The issue raised by the publicized paper is that the salt formation in which the WIPP repository is located contains much more water than was originally thought, and therefore within a few tens of years after repository closure, it would be a "wet" rather than a "dry" repository. The paper postulates scenarios of a slurry of brine and nuclear waste reaching the environment through fractures in plugs and seals of the underground excavations, shafts, and boreholes, or through "human intrusion" whereby someone might drill a well a few hundred years from now into the repository and inadvertently bring out the radioactive slurry to the environment. The pressurization of the waste "rooms" would occur due to the creep of salt, gas generation from radiolysis and bacterial decomposition of the organic matter in the waste drums. The Scientists contend that because of these conditions, the WIPP repository will not meet compliance with the EPA standards (40CFR191) that are applicable to WIPP.

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*The Subcommittee on Energy and the Environment of the U.S. House of Representatives Committee on Interior and Insular Affairs, hearing on H.R. 2504.

THE BRINE DATA

The Geological Characterization Report (Powers et al, 1978) for WIPP contains the results of fluid analyses on the Salado Formation salt rock samples. When bulk rock samples were heated to 300°C to recover all types of fluid, the total recovered amounted to less than 0.5% by weight of the rock. In the scientific reports and papers prior to 1985, brine migration caused by heat produced by high level waste was discussed, but no consideration was given to the potential problem caused by brine flow into the excavations, driven by pressure gradients only.

EEG first became aware of the existence of locally anomalous quantities of brine in the WIPP excavations in late 1983 when a 1 inch diameter, 14.8 ft. (4.5 meters) deep borehole (S850-C) drilled in the floor of the mine was found to contain approximately 2 liters of brine, the day after its completion. We considered this to be an unusual occurrence similar to the brine pockets occasionally encountered in the potash mines that are also in the Salado Formation. In June, 1984, we discovered during a visit to the WIPP underground that several more holes that had been drilled into the floor of the repository had filled up with brine and requested complete information on brine encounters at the WIPP repository horizon from DOE. In 1984-85, it became clear that the salt contained more moisture than was originally visualized and it did not need a thermal gradient (heat) to draw it out of the rock. The implication of this phenomenon on the long-term performance assessment still escaped the scientists in DOE, NAS and EEG.

The credit for pointing out the possibility of the repository becoming saturated with brine within a few hundred years after closure goes to Dr. John D. Bredehoeft, a U.S. Geological Survey hydrologist and a member of the National Academy of Sciences (NAS) Panel on WIPP. Dr. Bredehoeft presented his calculations at a meeting of the NAS WIPP Panel at Palo Alto, California in February 1986. Using actual permeability data of the Salado Formation, he calculated that the excavations would provide sufficient brine to saturate the closing rooms of the repository in a few hundred years. In ensuing discussion, the NAS Panel members asked DOE to develop scenarios and perform consequence analyses based on a brine saturated repository.

In June 1987, DOE published the "Phase I Report of the Brine Sampling and Evaluation Program" (Deal and Case, 1987). The report contains the following two important conclusions:

"It is clear from the preliminary data that significant pressure-driven brine inflows that are not the result of brine migration in a thermal gradient may occur after sealing and closure of the repository" (Deal and Case, p. ES-3)

"Although small when measured in terms of liters per day at any given location cumulative inflow volumes may be significant when measured in terms of the entire repository over periods of many years" (Deal and Case, p. ES-4)

COMPLIANCE WITH THE EPA STANDARDS

The criteria against which the performance assessment of WIPP would be judged are contained in the EPA Standards 40CFR191 that were promulgated in November 1985. In late 1986, the DOE awarded a contract to Sandia National Laboratory to conduct the performance assessment for showing WIPP's compliance with these standards. Sandia's Performance Assessment team presented the results of their preliminary calculations of some human intrusion scenarios to EEG in June 1987 that indicated that a repository of current design may give rise to releases from the repository that could violate the EPA Standards. A more detailed version of this presentation was made at the NAS WIPP Panel meeting in Idaho Falls in September 1987. Sandia's calculations show that given the best known inventory of WIPP waste, the rates of brine inflow, gas generation and room closure, between 5 and 15 m^3 (30 to 90 barrels) of "slurry" of brine and waste released to the surface will violate the EPA Standards. Two EEG presentations were also made at the Idaho Falls meeting; Dr. James K. Channell presented, "Estimating Quantities of Radionuclides Brought to the Surface by Human Intrusion into WIPP" and concluded that drilling into a brine slurry room might result in violation of EPA Standards even without considering scenarios involving the pressurized brine resevoir of the underlying Castile Formation. Lokesh Chaturvedi presented, "The Backfill issue and the First Seven Years of WIPP" and concluded that if only the amount necessary for performing genuine research experiments is brought to WIPP for the first five-year period, many potential problems can be avoided.

The "Scientists Review Panel on WIPP" has focused attention on the possibility of the waste slurry escaping to the environment due to pressurization and the as yet undemonstrated plugging and sealing systems, in addition to the human instrusion scenarios. Their calculations have not, however, followed the rigorous requirements of the EPA Standards concerning the knowledge of the waste composition, probabilities of breach events and consequence analyses.

PROPOSED SOLUTIONS

The Sandia Performance Assessment team has proposed a number of options to the DOE to resolve this potential problem. The most important recommendation is to modify waste and backfill to remove nearly all void space immediately. This would require extensive treatment of each drum before its final emplacement in the repository. The specific treatment may range from incineration and pelletization of the waste (meaning, burn to ashes and consolidate into spherical pellets) to crushing each drum and repackaging with cement. In addition, the planned backfilling with a crushed salt and clay mixture appears to be inadequate. Some sort of cement-based backfill will be necessary to reduce the empty space in the waste rooms in which brine-inflow may occur.

The "Scientists Review Panel on WIPP" has recommended a hold on work at WIPP, disallowing waste emplacement until the compliance with the EPA Standards (40CPR191, Part B) is demonstrated, and a review by an independent panel of scientists and engineers.

CONCLUSIONS

1. The concern about a "wet" repository is valid and real. It has been expressed by a Sandia National Laboratory team of scientists, the EEG, the NAS Panel for WIPP, as well as by the "Scientists Review Panel on WIPP."

2. There is a clear possibility of the present design not meeting the EPA Standard 40CFR191, Part B. If the repromulgated standard is more stringent than the present one, it may be even more difficult to meet.

3. The design changes proposed by the SNL scientists, that of reprocessing the waste drums and inclusion of a cement-based backfill, are major and costly.

4. If the DOE does not change its present plans to bring up to 125,000 drums of waste and places them underground without backfill for the first years, they may be faced with the following two options:

(a) Starting in 1993, for the next 5 to 10 years, each drum may have to be retrieved, reprocessed and re-emplaced with specially formulated backfill material.

(b) To avoid the additional expense and delays to meet the EPA Standards, DOE may seek exemption from EPA for this waste and leave it without its being in compliance with the standards and in a potentially dangerous state.

<u>RECOMMENDATIONS</u>

The situation demands that the DOE be asked to take the following steps immediately:

1. Change the plans for the first five years to store only the amount of waste underground necessary for demonstrably valid and genuine experiments.

2. Perform carefully controlled experiments to measure actual brine inflow into a WIPP repository "room" and consequence analyses to assess the impact of the brine-filled repository and other scenarios on the compliance with the EPA Standards. Publish the results in a reviewable scientific paper.

3. Change the design as required by these calculations and make plans to reprocess the waste and design a suitable backfill.

4. Only after these steps have been taken and the calculations, design, and plans are reviewed by the EEG, EPA, and the NAS scientists, proceed with the full operational schedule.

5. Considering that the WIPP repository is a much needed final solution to the defense transuranic waste disposal problem, delaying operational timing by months to even a few years to make it a safer repository will be wise. We do not know of any compelling need to start storing waste underground at WIPP, before the final emplacement mode, needed reprocessing of waste drums and the backfill design are developed to comply with the EPA Standards.

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ASSESSMENT OF BRINE INFLOW TO WIPP DISPOSAL ROOMS*

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BRINE INFLOW MODEL

We have a predictive model for the movement of brine to WIPP excavations from WIPP rock salt [1,2]. This model is based on well known physical processes of groundwater flow in granular deposits. All values for model parameters are based on independent measurements of brine and host rock salt properties [1,2,3,4], and brine movements calculated from the model are consistent with the body of existing data for brine accumulations in WIPP underground test boreholes [1,2,5]. Uncertainties in parameter estimation are in the order-of-magnitude range. The details of the model and its applicability to WIPP rooms and test boreholes rest upon a number of assumptions that are being subjected to further testing. Experiments are underway in the WIPP specifically for that purpose.

According to the model, brine flows in intergranular spaces within the polycrystalline host rock salt under the driving force of preexisting hydrostatic (groundwater head of approximately 1000 psi) or lithostatic (overburden pressure of approximately 2000 psi) pore pressure toward the atmospheric pressure at excavation walls. The capability of the host rock salt to allow flow under this driving force, commonly expressed as a "permeability", is very small, in the range of 1 to 10 nanodarcies. These permeability values are in good agreement with independent WIPP in situ fluid flow measurements [3,4]. The Darcy flow process in geologic materials is well understood, and the describing mathematical formalism is accepted by the scientific community.

WIPP DATA BASE

Permeability values for the model were derived from WIPP in situ test and brine sampling data. Darcy flow permeabilty values calculated from IT Corporation's WIPP brine sampling data [5] can be described reasonably well by a typical lognormal distribution with a logarithmic mean of 3.5 nanodarcy. A lognormal distribution of permeability values is a common observation for other rock types [6]. Permeability values similarly calculated from Sandia moisture release data (Rooms A1 and B) [1,2] are in the range of 2 to 9 nanodarcy. All of these derived values are consistent with independently measured in situ permeabilities [3,4]. The derived permeability values were obtained from the WIPP data base that was evaluated by the following method.

D. F. McTigue [7] evaluated IT Corporation's brine sampling data [5] as an extension of the WIPP data base for modeling brine inflow to waste disposal rooms. Deal and Case [5] monitored 54 drillholes throughout the WIPP, most of them for about 500 days. They report data and time histories of total influx for 20 of these holes [5]. The inflow rates for two of the holes fell to essentially zero after 600 days. The remaining 18 holes were considered for this evaluation.

The IT Corporation brine sampling data were evaluated by calculating with our radial Darcy flow model for the WIPP [1,2] an apparent host rock permeability value for each sampled hole. Model parameters were given the independently derived values that were used previously [1,2]. Inflow rate data at approximately 500 days were used, and the permeability was calculated numerically for time equal to 500 days and for the preexcavation pore pressure equal to approximately hydrostatic pressure at a depth of 600 m.

A histogram of number of drillhole observations versus the logarithm of the calculated apparent permeability is shown in the attached figure. The histogram tends to approximate the superimposed lognormal distribution (represented by the solid bell curve). A lognormal distribution of permeability values is a common observation for other rock types [6].

Apparent permeabilities were also calculated similarly (but using relationships that are appropriate for shorter times after excavation) from Sandia's moisture release data taken in Rooms A1 and B before heaters were turned on [1,2]. The range indicated in the attached figure is for apparent permeabilities calculated from the range of 5 to 15 g/day observed during the moisture release experiments. The indicated range for the Sandia moisture release data is at the mean of the lognormal distribution for the IT Corporation brine sampling data.

These observations must be qualified by a reminder that uncertainties in parameter estimation are in the order-of-magnitude range. The details of the model and its applicability to WIPP rooms and test boreholes rest upon a number of assumptions. These assumptions are likely to yield conservatively large values for long term brine inflow. Critical assumptions concerning flow mechanism will be tested with ongoing and planned WIPP experiments. Inaccuracies stemming from idealized geometries are being investigated with more detailed numerical calculations.

CALCULATED BRINE ACCUMULATIONS IN WIPP WASTE DISPOSAL ROOMS

Expected accumulations of brine in typical WIPP waste disposal rooms during 100 years after the operational period have been calculated by numerical methods [8] using a mathematical description for this model. WIPP disposal rooms filled with waste and backfilled are expected to close due to host rock salt creep in about 100 years, preventing further accumulations of brine. A typical room has an initial excavated volume of approximately 3600 cubic meters (950,000 gallons). The results of these calculations are in the following table:

Host Rock Permeability, Nanodarcies	Pre-Excavation Pore Pressure	Cumulative Brine Volume in Typical Waste Disposal Room after 100 Years, Cubic Meters, (Gallons), (% of Initial Room Volume)
1	Hydrostatic	4 m^3 (1000 gal) (0.11%)
1	Lithostatic	9 m^3 (2400 gal) (0.25%)
10	Hydrostatic	17 m^3 (4500 gal) (0.47%)
10	Lithostatic	43 m^3 (11000 gal) (1.19%)

Other less complex calculations for idealized room geometries (long cylinders) provided confirmation of the above results, yielding volumes in the range of approximately 1 to 40 m^3 [9].

To gain some perspective on these quantities, one can visualize a layer of brine 1.8 inches thick on the floor of a 13 foot high room as the equivalent of 43 m^3 of brine in a typical WIPP waste disposal room. This worst case volume of brine is 1.2 % of the initial room volume, about the same as the quantity of brine in the salt that was removed by mining the room. Backfill materials such as crushed salt and bentonite clay can readily absorb such a quantity of brine without becoming saturated or degraded.

ABSORPTION OF ACCUMULATED BRINE BY BACKFILLS

Mined WIPP salt backfill alone can absorb 40 m^3 of accumulated brine in a disposal room (93% of the predicted worst case 43 m^3), according to conservative estimates of room backfill quantity and water absorption capacity [10]. The absorption capacity is the difference between the measured water content (0.5 wt% or less) of mined WIPP salt backfill material [11,12] and the water content (2.5 wt%) of physically strong blocks pressed from WIPP crushed salt [13].

A tailored backfill material mixture of 30 wt% bentonite in crushed WIPP salt can absorb 120 m^3 of accumulated brine [10]. That is about 3 times the predicted worst case 43 m^3 in 100 years. This result was also based on conservative estimates of room backfill quantitity [10] and water absorption capacity for bentonite [14]. Bentonite in this WIPP room backfill mixture has the capacity to absorb 90 m^3 of water without becoming water-saturated [15]. This absorption capacity takes into account water that would be pre-absorbed from WIPP air at approximately 70% relative humidity, an actual value that is currently being measured by Sandia in WIPP boreholes (ongoing Room D brine inflow and humidity experiments).

Tailored backfill mixtures with bentonite as a water absorber have always been considered in WIPP backfill investigations. Bentonite mixed with 70 wt% WIPP crushed salt is currently being tested in WIPP simulated CH TRU waste technology experiments [16]. The long term stability of bentonite in contact with WIPP brines is supported by reported Sandia studies [17].

SUMMARY

Water-absorbing tailored backfill materials can readily absorb the maximum expected 100-year brine accumulations in WIPP disposal rooms without becoming brine-saturated. Crushed WIPP salt backfill alone can absorb almost all of the maximum expected brine accumulation. Salt creep is expected to close these rooms within 100 years, preventing further accumulations of brine. Expected brine accumulations were calulated with our predictive Darcy flow model for the movement of brine to WIPP excavations from the host rock salt. This model is based on well known physical processes of groundwater flow in granular deposits. All values for model parameters are based on independent measurements of brine and host rock salt properties, and brine movements calculated from the model are consistent with the entire body of existing WIPP brine inflow data. The Darcy flow process in geologic deposits is well understood, and the describing mathematical formalism is accepted by the scientific community.

Permeability values in the range of 1 to 10 nanodarcy were derived from WIPP data and used in the model to calculate cumulative brine inflow volumes of 1 to 43 m^3 per room in 100 years. A room backfill with 30 wt% bentonite in crushed WIPP salt could absorb 120 m^3 of accumulated brine per room, or about three times the maximum expected 100-year accumulation. Mined WIPP salt backfill alone can absorb 40 m^3 of accumulated brine.

Uncertainties in parameter estimates are in the order-of-magnitude range. The details of the model and its applicability to WIPP rooms and test boreholes will be tested further with WIPP experiments and more detailed numerical calculations.

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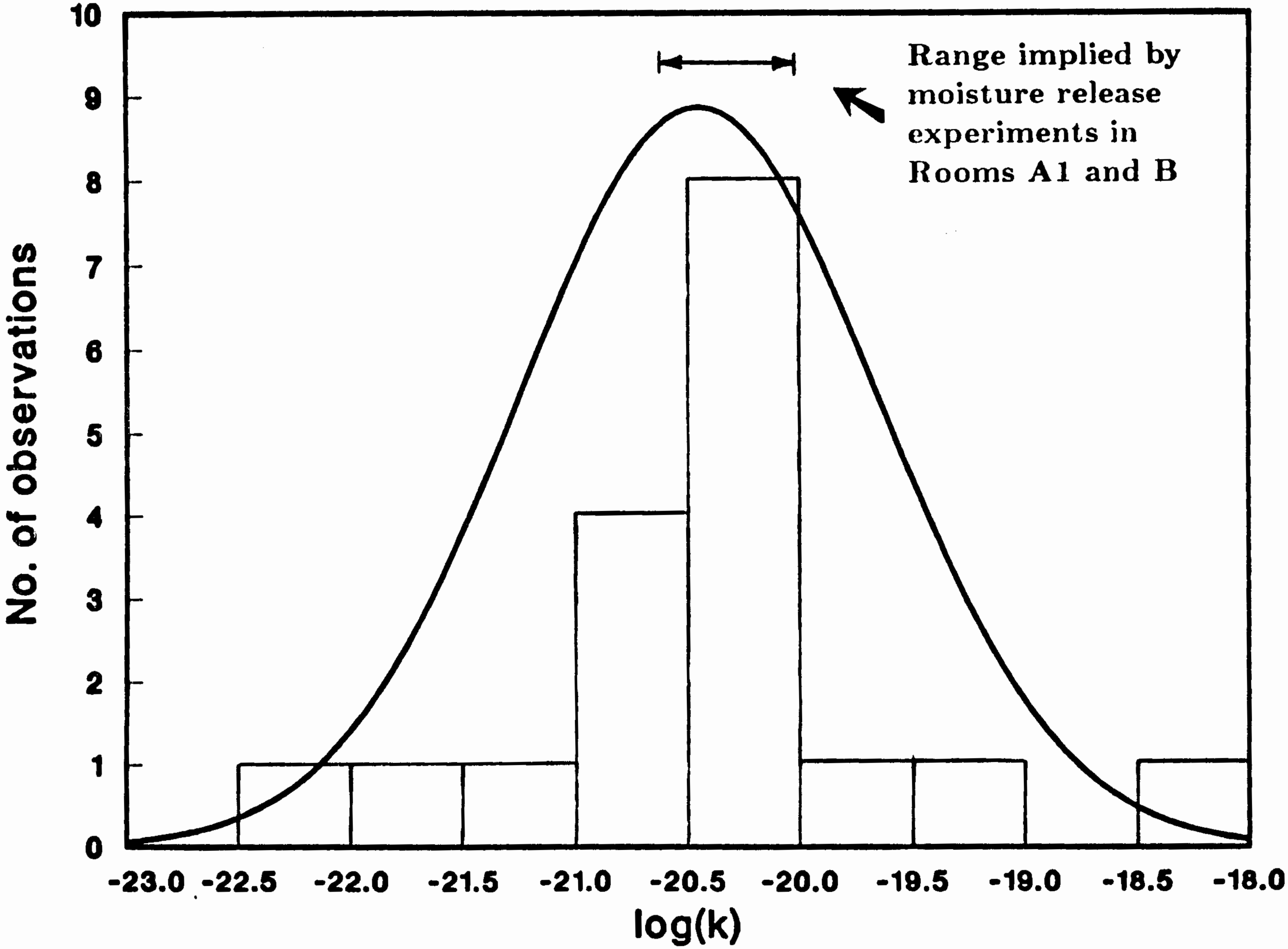

Range implied by moisture release experiments in Rooms A1 and B
No. of observations
log(k)
10
9
8
7
6
5
4
3
2
1
0
-23.0
-22.5
-22.0
-21.5
-21.0
-20.5
-20.0
-19.5
-19.0
-18.5
-18.0

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Is WIPP Salt "Dry" -- An Alternative Hypothesis

John D. Bredehoeft

Abstract

Data from the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico suggest an alternative hypothesis to the widely held view that salt in a geologic environment below the water table is "dry" and impermeable. Such a revision in thinking does little or nothing to jeopardize WIPP as a suitable repository, but it does suggest that "the salt section, which for the most part is of low permeability and low porosity, is saturated with brine". The implication of this alternative hypothesis is that a repository in salt will fill with brine once the ventilation of the facility ceases to remove moisture. The rate of inflow to the facility will depend on the permeability of the salt. Data from the WIPP facility suggest an undisturbed salt permeability of approximately 10 nanodarcies (10^{-12} cm/sec). Given such a low permeability the rate of brine inflow to an underground facility will be quite low.

Introduction

The National Academy of Science Committee that considered geologic disposal of nuclear waste in the mid 1950's recommended salt as a repository medium, partly because of its high thermal conductivity and because it was believed to be dry (perhaps the appropriate thought is: impermeable). Certainly, the fact that Paleozoic salt deposits exist in many parts of the world is evidence for very low rates of dissolution by moving groundwater. The fact that the dissolution rates were so small led many scientists to the conclusion that the salt beds were nearly impermeable. The major source of brine was thought to be fluid inclusions within the salt crystals which could migrate through differential solution toward a source of high heat. The idea that salt was uniformly "dry" was revised when exploratory drilling in the vicinity of the WIPP facility in New Mexico encountered brines within the Castile Formation, an evaporite deposit below the Salado Formation. The brine reservoirs were thought to be isolated pockets of brine in an otherwise "impermeable" salt section.

On the basis of data collected in association with the Waste Isolation Pilot Plant (WIPP) in New Mexico, an alternative hypothesis regarding the pore fluid regime within the salt itself is suggested in this paper; that is: "the salt section, which for the most part is of low permeability and low porosity, is saturated with brine". This hypothesis is consistent with a number of recent observations both in boreholes and the mine. Some of these observations are enumerated below:

1. Boreholes within the WIPP mine produce fluids. Admittedly, these occurrences are often correlated with the anhydrites, zones of higher permeability. However, one must imagine a source of fluids for the higher permeability layers within the overall evaporate body.
2. There are salt efflorescences throughout the WIPP mine. These efflorescences appear to be stratified, which would suggest that some layers are more permeable than others.
3. Testing of experimental heater holes, prior to heating, produced brine at a rate of 10 to 12 grams per day.
4. Boreholes completed in the evaporite section fill with brines. Tests on these holes show that they are not impermeable. Figure 1 is a plot of pressure build-up from two conventional drill stem tests performed in a test borehole in the Permian Salado Formation at the WIPP site. In each case the fluid pressure build-up, following a period flow to the well, was quite rapid, indicating a finite and measurable permeability.

Figure 1. Results from two drill stem tests in salt of the Permian Salado Salt Formation. In each test two periods of flow are followed by periods of pressure build-up (data courtesy of Sandia National Laboratory).

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5. Finally the in-situ permeability measurements indicate that although the salt has permeabilities ranging to a lower limit of approximately a nanodarcy, it is measurable. In addition, the porosity also is low, less than 0.01. The in-situ permeability

and porosity measurements are summarized in Table 1. The data clearly indicate that the salt of the Salado Formation at the WIPP site is not impermeable.

Table 1. In situ permeability measurements of salt associated with the WIPP repository. (data courtesy of Sandia National Laboratory).

<u>Repository Inflow - Numerical Calculation</u>

It is of interest to do a few simple calculations on the rate of brine inflow into the WIPP repository using as a working hypothesis--that salt is saturated with brine. In order to make the calculations several simplifying assumptions are made; an attempt is made to justify these assumptions as at least reasonable for a first-order type calculation. Implicit in the calculations is the assumption that the flow can be described as flow in a porous medium. The test data which indicate low permeabilities, ranging from 1 microdarcy to perhaps a nanodarcy, suggest that this assumption is reasonable. One can also ask, does Darcy's law describe flow at such low permeabilities. Perhaps the most careful investigation of this question was done on Kaolinite clays by Olson (1966, 1969). Olson saw no departure from Darcy's law at permeabilities as low as 10 microdarcies. In making the calculations the assumption was made that the flow process within the salt can be described as flow in a porous medium and that the partial differential equations which describe this as a transient process are applicable.

There is considerable evidence that the mining process creates a disturbed zone in the immediate vicinity of the mine. Many of the higher permeability values are believed to be the result of this near-field disturbance. Figure 2 is a plot of gas permeability versus distance from a mine opening at the WIPP facility which is thought to show the effect of the mining disturbance.

Figure 2. Permeability versus distance from a mine opening, measured in the WIPP mine. (courtesy of Sandia National Laboratory).

The long-term flow of fluid into the WIPP repository will be controlled by the far-field properties of the salt itself. For the purpose of these computations the near-field disturbed zone is neglected. The lower, measured values of permeability and porosity are assumed to represent far-field properties. In neglecting the near-field disturbance the assumption is made that the far-field properties extend to the workings; this is a conservative assumption. The effects of the disturbed, near-field can be included in later calculations should that be of interest.

The "specific storage", Ss, a parameter in the transient flow equation is a compressibility factor which includes the compressibility of both the brine and salt. Salt at the depth of the WIPP facility behaves plastically. In order to estimate the specific storage the elastic properties of salt were used to obtain a lower limit for the specific storage. Assuming a porosity of 0.01 and elastic salt behavior, data taken from Clark (1966) suggest a specific storage of approximately, 10^{-6} m^{-1}; assuming elastic behavior for the salt gives a specific storage that is probably too low. The specific storage, Ss, was varied by two orders of magnitude in order to gain some feel for the effects of plastic salt behavior on the results.

The hydraulic head within the salt is an issue of continued discussion. If the system has reached an equilibrium state, then one would expect a more-or-less hydrostatic fluid pressure. On the other hand, if the salt is continually deforming and tending to decrease the available pore space at a sufficiently high rate, then one might expect that the pore fluid pressure would be above hydrostatic. One can also see that the disturbance produced by the mining could reduce the pore pressure in the vicinity of the mine. As part of any future experiment, one would like to measure the undisturbed pore fluid pressure.

Since the elevation selected as a reference datum for hydraulic head is purely arbitrary, it is convenient to choose the base of the tunnel as the reference for the calculations (see Figure 3). For the purpose of this analysis the initial head in the salt was taken to be 600 meters above the floor of the tunnel, an approximately hydrostatic initial condition. Both the overlying Permian Rustler Formation and the underlying Permian Bell Canyon Formation consist of more permeable, water bearing rocks which can serve as sources of groundwater. For these computations heads in both these units were held constant, equal to an initial 600 meter, hydrostatic head.

Once the tunnel is excavated the assumption is made that the pressure in the tunnel remains atmospheric indefinitely. This assumption is appropriate as long as the repository is operating. Once operation ceases, the tunnel will begin to fill with brine, and the boundary conditions within the tunnel will change. No attempt has been made to simulate changing conditions within the tunnel following its closure.

The question arises whether to attempt an analytical solution or solve the basic flow problem numerically. I have chosen to pose the flow problem as flow in a cross-section taken at right angles to a long tunnel. The problem is then one in two space dimensions, x and z. The problem is solved numerically using a finite difference code. The near-field portion of the finite difference grid is drawn on Figure 3.

Figure 3. Near-field portion of the finite difference grid used to simulate flow to the repository.

Flow is symmetric about the center-line of the tunnel, and therefore, only one half of the problem is computed. Near the tunnel the finite difference cells are 1 meter by 1 meter. These are increased geometrically in size as we move away from the tunnel, as illustrated on Figure 3. The region of flow simulated is from the overlying Rustler Formation and to the underlying Bell Canyon Formation. Horizontally, the cross-section considered in the calculations extend to a distance of approximately 5 kilometers out from the tunnel. The tunnel itself is 4 meters high by 10 meters in width. Because of the symmetry of the problem the calculations are made from the center-line of the tunnel outward (only flow in one-half the cross-section is simulated).

Results of Calculations

The results of the calculations are shown on Figure 4. The graph plots the inflow to one half of the tunnel; the calculated influx is per unit length of tunnel.

Figure 4. Plot of simulated inflow to a one meter length of an infinite tunnel.

At a permeability of a microdarcy (10^{-6} darcy) the calculations indicate a range in influx from approximately 1 liter per day per meter of tunnel to a rate which stabilizes at 0.3 liters per day at a period of about 100 years. Assuming a tunnel volume of 20 cubic meters (4 x 5 x 1 m), 20,000 liters, it would take approximately 50 to 100 years to fill the tunnel (assuming the tunnel remained undeformed and at atmospheric pressure). For the microdarcy permeability, the calculations were made for both an Ss of 10^{-6} and 10^{-4}, as indicated on Figure 4.

As one reduces the permeability the rates of influx decrease by an order of magnitude. At a permeability of 10^{-7} darcy, it takes approximately several thousand years for the rate to stabilize at 0.03 liters per day. At 1^{-8} darcy the inflow rate at early time, approximately one year, is of the order of 0.02 liters per day. At this low permeability the rate stabilizes at 0.003 liters per day per meter of tunnel, at about 30,000 years. At this low rate it would take several thousand years to fill the initial void space with brine. Of course the problem is more complex since the tunnel is also deforming plastically at the same time.

Comparison of Calculations and Experimental Results

In one set of underground experiments at the WIPP facility a number of holes were drilled into the floor of one experimental room and heaters were placed into the holes to simulate the effect of storing hot nuclear waste cannisters. The moisture flux was carefully measured before and during heating in two of the holes. Two other holes were unheated and the moisture flux into the holes measured. Moisture flowed into all four holes; in both the heated holes the influx was significant before heating. The rate of inflow ranged from 5 to 15 grams of brine per day in the four holes. Figure 5 is a plot of the moisture influx into Borehole B041, one of the heated holes.

Figure 5. Moisture influx into one of the experimental heater holes in the WIPP facility. (data courtesy of Sandia National Laboratory).

The moisture influx data, can be fit to the numerical calculations, Figure 4. These data suggest a permeability of the Salado Salt of approximately 8 or 9 nanodarcy. The heated hole data as adjusted by Nowak (1986) is plotted on Figure 4. These calculations would suggest that a tunnel 1,000 meters long would have a total influx in the first several years following mining, ranging from approximately 10 to perhaps 100 liters per day if the permeability were in the range from 10^{-7} to 10^{-8} darcy.

Further Investigations

A large scale permeability experiment in which the influx would be integrated over a fairly large volume of a salt mine is comparable to a room-scale rock mechanics experiment. The justification for a large-scale permeability experiment is directly analogous to the justification for a room-scale rock mechanics experiment. The difficulty with a room-scale experiment is that an unsaturated zone, which could make the results more difficult to understand and analyze, may form within the salt surrounding the opening.

The alternative to a room-scale experiment is a series of experiments done in small-diameter boreholes. In concept a small-diameter borehole would be drilled either horizontally, or vertically out from the mine workings. The quantities of fluid flowing into the hole would be monitored with time. These data could then be analyzed to determine a bulk permeability.

In designing the experiment, one would like to maintain the humidity within the borehole such that it would not tend to "dry" the surrounding salt and create an unsaturated condition. This condition seems best achieved by leaving some of the produced brine within the borehole at all times. The humidity within the hole could then equilibrate with the vapor pressure of the brine. Presumably, the surrounding salt would not dry out under such a borehole condition. This would suggest sealing the borehole and only partially removing the brine. These are only suggestions, the details of such experiments need careful consideration and planning.

An important experiment is to attempt to measure the "virgin" pore pressure in the salt in a borehole. This requires sealing a

Acknowledgment

The fact that this paper can be written at all is a tribute to the Department of Energy and, in particular, its principal scientific advisor, the staff of Sandia National Laboratory. They have conducted a carefully conceived and executed scientific investigation of the WIPP facility which has been designed to assure the scientific community and the public, that disposing of nuclear waste in WIPP is a prudent undertaking. It is the data collected by their investigation which make this paper possible. I would also like to thank my colleagues on the NRC Board of Radioactive Waste Management WIPP Panel. Our panel discussions, and at times heated debate, served to sharpen the ideas presented in this paper.

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PERMEABILITY DATA - SALADO FORMATION

Depth		Permeability (Darcy)		Porosity
	Drill Stem Tests	(Range in Data)		
AEC 7				
1807-1907	S^3 - Constant Pressure Gas		3×10^{-6}	
2207-2307	S^3 - Constant Pressure Gas	2×10^{-5}	1×10^{-5}	
AEC 8				
1433-1486	Conventional DST	7×10^{-7}	7×10^{-8}	
2014-2094	Conventional DST	3×10^{-6}	7×10^{-7}	
2512-2618	Conventional DST		2×10^{-6}	
2512-2623	Conventional DST		3×10^{-6}	
2623-2713	Conventional DST	3×10^{-5}	7×10^{-8}	
2623-2874	Conventional DST	6×10^{-6}	4×10^{-7}	
Cabin Baby				
757-2717	Conventional DST	8×10^{-8}	9×10^{-9}	
	Wipp In-Situ Tests - S^3			
L2PH01				
2M	Test 1	6×10^{-7}	3×10^{-7}	0.01
2M	Test 2		2×10^{-8}	0.01
6M	Test 3		1×10^{-9}	0.001
L2PU01				
2M	Test 4		4×10^{-8}	0.001
6M	Test 6		9×10^{-9}	0.001
7M	Test 7		1×10^{-8}	0.005
L2PU02				
2M	Test 10 Clay & Anhydrite Seam		3×10^{-3}	0.01
L1PU01				
14M	Test 12		3×10^{-10}	0.001
L2PD01				
3M	Test 9		6×10^{-7}	0.001
10M	Test 8 Marker Bed 139	8×10^{-4}	8×10^{-5}	0.01
L1PD01				
12M	Test 11		3×10^{-9}	0.001

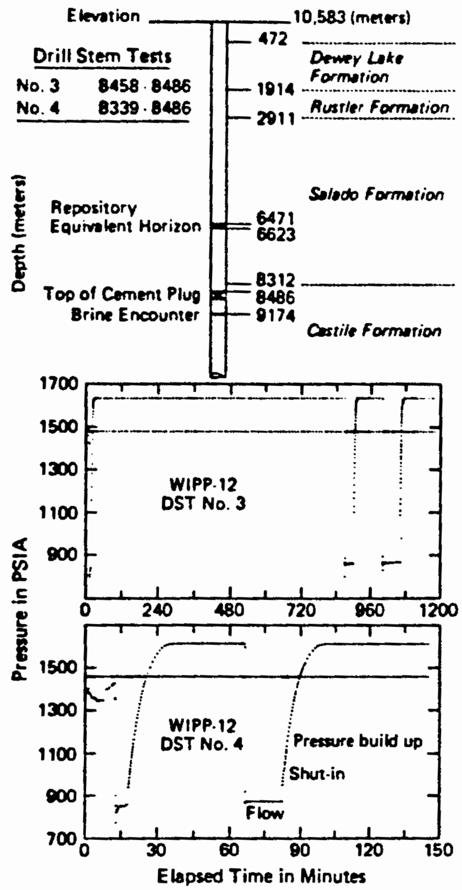

FIGURE 1

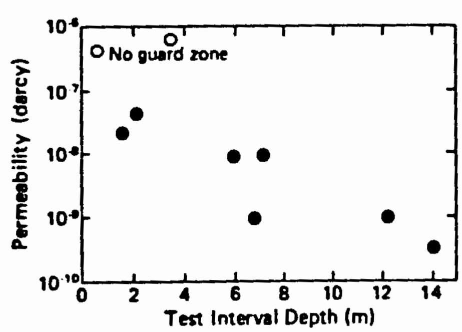

FIGURE 2

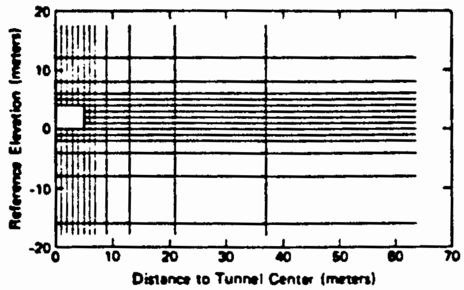

FIGURE 3

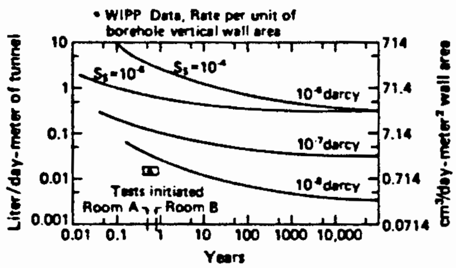

FIGURE 4

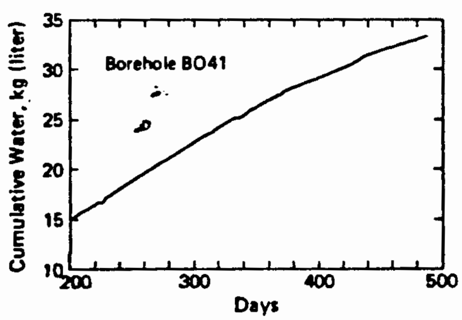

FIGURE 5