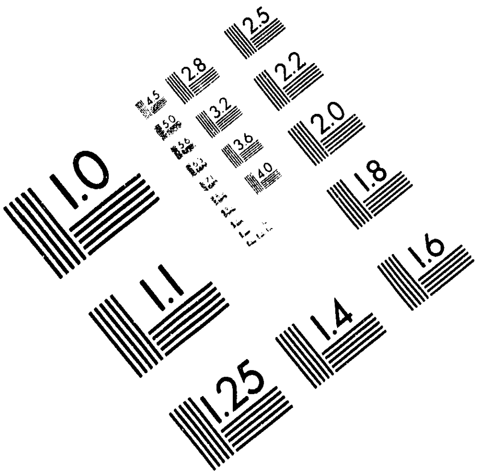

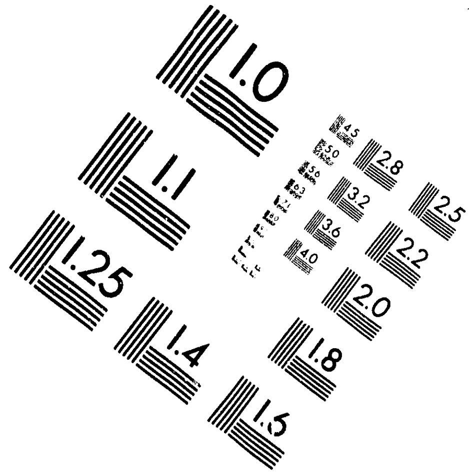

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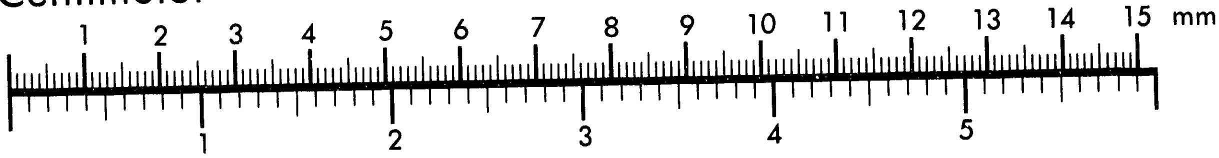

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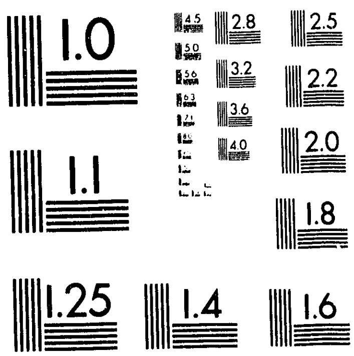

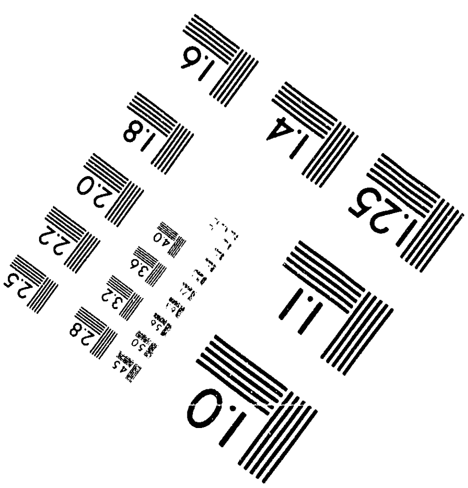

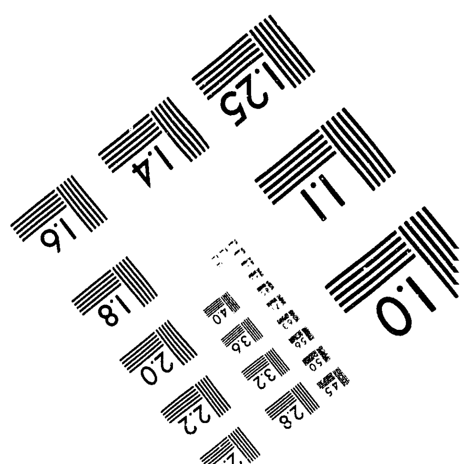

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GAS BARRIER DESIGN FOR THE WIPP

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INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is planned as the first mined repository for transuranic (TRU) wastes generated by defense programs of the United States Department of Energy (DOE). In coming years, tests with radioactive wastes are planned to be conducted at the WIPP. Potential tests include evaluation of gases generated by wastes emplaced in mined alcoves. Barriers must be installed in the entries to the test alcoves to limit gas release during testing. This paper discusses several rock mechanics issues involved in the design of an Alcove Gas Barrier (AGB) for use in these potential tests.

The unique requirements placed on a gas barrier, when coupled with the geologic setting and strict regulations, make the AGB design challenging from several perspectives of rock mechanics. The AGB structure will be placed in the WIPP underground, which comprises a layered evaporite sequence of rock. A schematic of the design as it might appear in the WIPP underground is shown in Figure 1. The underlying requirement is that the AGB reduce gas leakage from a test alcove to an acceptable limit. The most likely route for gas leakage is through a disturbed rock zone (DRZ), which develops in response to the excavation. Among other effects, the loading on the structure is a function of the geometrical arrangement and time, including considerations of installation and service life. Resolution of design issues also requires a defensible measure of conservatism. These considerations give rise to several issues in rock mechanics which are the emphases of this paper.

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ROCK MECHANICS DESIGN CONSIDERATIONS

The rock mechanics considerations of the AGB design consist mainly of numerical modeling studies which yield information on three principal concerns:

1. The development and extent of the DRZ after excavation of the alcove entry but before liner installation.
2. The eventual loads to be borne by the AGB as a consequence of salt creep.
3. The response of the surrounding rock to the presence of the lining in terms of healing of damage in the DRZ in salt and the arresting of further damage in interbeds.

Items 1 and 3 pertain to performance of the AGB system, and this may be the first time such considerations have been applied in the field of rock mechanics. Item 2 determines the structural design load and its distribution, which are more conventional modeling goals. Together, these results provide insight into how well the AGB might function.

Three types of analyses are involved in support of the design: rock mechanics, structural, and fluid flow. The rock mechanics analyses provide information on deformations and stresses as a result of the excavation and the later installation of a rigid sleeve. The rock mechanics analyses also evaluate the development of a DRZ. The structural analyses for concrete and steel in the composite liner use prevailing industrial codes and standards to the extent applicable and will not be discussed in detail here. Some relatively simple fluid flow analyses were used to calculate a range of possible gas-leakage rates through components of the rock and AGB liner. Although the specifics are not discussed in this paper, the analyses demonstrated the overriding concerns of flow through nonsalt strata. The amount of flow from the alcove depends in part on the minimization and remediation of rock damage, and limiting gas flow will be discussed in that context here. Ultimately, a demonstration of the AGB by deployment in the field could serve to validate the analyses.

Soon after an opening is mined at the WIPP horizon, a DRZ will form because of stress relief and creep. A DRZ has the following characteristics: 1) an increased volume resulting from fracturing, 2) decreased load-bearing capacity, and 3) increased fluid permeability. The DRZ in salt will grow with time and could form a major leak passageway from the test alcove. However, if the salt is prevented from creeping into the opening by a rigid liner or sleeve, the DRZ in salt starts to heal. The AGB is designed to arrest further development of the DRZ around the opening and induce back pressure on the salt to promote healing of the DRZ. The rigid sleeve also stops further deformation of Marker Bed 139 (MB139), a 1-meter thick anhydrite layer approximately 1 meter below floor level. If fractured, MB139 could be a dominant leak path, and it is not expected to heal naturally. Eventually, stresses in the salt behind the liner are expected to return to their premining state; the mean stress increases and the deviatoric stresses decrease. The rigid-liner concept forms the general framework of the design considerations.

DISTURBED ROCK ZONE

A considerable body of laboratory work supports the notion that dilation in salt can be discussed meaningfully in terms of the first invariant of the stress tensor, I_1, and the second invariant of the deviatoric stress tensor, J_2 (see Van Sambeek et al. [1]). An approximate mathematical limit surface separating the non-dilating and dilating stress combinations was used for purposes of the AGB design:

$$\sqrt{J_2} = 0.27 I_1 \quad .$$

Although this simple dilation criterion is acceptable for our immediate needs, the definition of the surface will probably become more sophisticated as the science is advanced. Whenever a stress condition exists that causes dilation, it is expected that the permeability in salt will be enhanced by microcracking in the salt. A quantitative relationship between dilation and permeability has not yet been developed. It is expected, however, that the limit surface also defines the stress combinations that promote healing of preexisting microcracks.

Using the dilation criterion, contours of the dilation zone in terms of damage factors can be post-processed from calculated stress histories. A damage factor of $D > 1.0$ means the stress state is promoting dilation. An example of a dilating zone surrounding the circular opening just before AGB installation is shown in Figure 2. The use of damage-zone contours allows assessment of relative disturbance and its extent. The dilation zone expands as time goes on, and stresses are redistributed unless the inward creep of the salt is halted. Plane strain analyses which delineate the salt DRZ were completed for a sequence of geometrical openings including rectangular, horseshoe, and circular. A comparison of the DRZ was then possible between a freely creeping excavation and an opening restrained by a rigid liner.

A DRZ also develops in interbeds and clay seams, which are represented schematically in Figures 1 and 2. The damage that occurs in the interbeds is believed to be primarily a consequence of differential displacement and bending. The deformation in the interbeds is caused largely by creep of the salt as it forces the interbeds to move with it. Preexisting, healed fractures in the interbeds are expected to be opened or sheared under such conditions. The degree of damage in MB139 is, therefore, strongly related to the amount of creep deformation in the salt. One design consideration is to minimize the uplift and flexure of MB139 and differential movement of the clay seams, thereby limiting potential enhancement of permeability. A rigid-liner concept accomplishes this design consideration.

NONLINEAR CREEP ANALYSES

Simulation of the salt response used the two-dimensional, finite-element code SPECTROM-32 [2]. A multimechanism constitutive model of salt deformation is used, and is described in detail elsewhere in these proceedings by Munson and co-workers [3]. Most models pertaining to this design are plane-strain cross sections of the various opening shapes and surrounding simplified stratigraphy such as shown in Figure 2. In contrast to the plane-strain representation, estimate of end effects and longitudinal loading used an axisymmetric model and an all-salt medium.

In the analyses, the access entry to the hypothetical alcove is instantaneously mined and the salt allowed to creep unrestrained, undergoing stress redistribution for three months (six months in some additional studies) before installation of the rigid sleeve. A plot of a typical stress path at the midlength of the liner is shown in Figure 3. A lithostatic state of stress is assumed before the excavation is created (I_1=44.5 MPa, J_2= 0 MPa). The excavation immediately creates a stress difference sufficient to cause dilation in the salt ($\sqrt{J_2}>0.27I_1$). Before installation of the liner, which is assumed to require three months, the stress is calculated to change as depicted in Figure 3. Immediately after installation of the liner, the stress at this example point is seen to reapproach a lithostatic condition over the design life of the liner.

Longitudinally, there is an end-loading effect in the normal stress distribution. For a length of sleeve less than about three times its diameter, the end-loading effect extends over the entire length, and the loading can ultimately exceed the lithostatic stress magnitude. For lengths of more than three diameters, the liner loading is somewhat less than lithostatic at the midlength, but still greater than lithostatic at the ends. The end-loading increase is a three-dimensional effect and cannot be observed in the plane-strain analyses. In this particular design, the stress concentration at the end of the AGB is mitigated by including a portal structure. Results of the longitudinal liner-loading analyses are plotted in Figure 4. From the center of the AGB to the end, the liner loading increases. Without the portal structure, the stresses become very large. With the portal structure and the excavation associated with it, the stress concentration on the liner is reduced appreciably.

DISCUSSION

Three important points were recognized early in the development of concepts for the AGB. First, the performance requirements for the system are quite stringent. Second, the AGB will be a first-of-a-kind design and construction procedure in salt. Finally, while analyses of structural behavior and gas flow are important, the current analytical capabilities and available data are such that it is unlikely that analyses will be able to prove or disprove the ability of the design to meet performance requirements. Because of the uniqueness of this design project, a design philosophy was adopted.

Aspects of the design philosophy include:

1. Limiting disturbance of the formation.
2. Limiting gas flow through the AGB and surrounding rock.
3. Using available, proven technology where possible.

Limiting Disturbance

The undisturbed rock at the WIPP is relatively impermeable. Therefore, limiting the rock disturbance caused by excavation of the AGB opening will increase the probability of achieving a low gas-leakage rate through the rock. The disturbance of rock was minimized in the design by:

1. Using the smallest possible circular cross section for the opening.
2. Developing a design that allows an expeditious excavation and AGB installation schedule.
3. Increasing the distance between the floor of the opening and the top of MB139.
4. Providing gradual transition zones between the circular opening for the AGB and the rectangular access drift.

A circular cross section for the AGB opening is the optimal shape for minimizing stress concentrations caused by excavation and the subsequent damage to the host rock caused by salt creep. Although it does not directly influence disturbance of the rock, a cylindrical lining is a preferred structural shape in terms of resisting the liner loading that develops as the structure restrains the creep in salt. The location of the clay seams was also considered in the shape selection and in determining the elevation of the AGB opening. A relatively short construction schedule was imposed because damage to the rock is tied to the creep of salt and is therefore cumulative with time. And finally, some fine tuning of the transition from circular to rectangular is incorporated into the design layout.

Limiting Gas Flow

The AGB is expected to minimize potential gas flow from the alcove. The methods and materials used in the design to limit gas flow (leakage) from the test alcove include:

1. Healing of the salt DRZ by restraining creep closure by using a rigid lining and thereby inducing stress conditions favorable to healing damaged salt.
2. Provisions for remedial grouting of the non-salt DRZ at four intervals along the length of the AGB.
3. Provisions for sealing clay seam F, which is intersected by the opening.
4. Using three distinct transverse membranes to contain any gas flow within the annular space.

5. Pressure grouting the annulus between the precast ring segments and the longitudinal membrane to fill the annular space completely.

6. Using a longitudinal membrane to minimize the potential for a flow path at the interfaces.

Available Technology

Even though the AGB is a first-of-a-kind structure, available technology is either used or adapted throughout the design. Use of available technology (and avoidance of developing new technology) is expected to improve the likelihood of a successful application.

The concrete portion of the AGB uses conventional, high-strength concrete technology. Moreover, the structural design uses appropriate steel and concrete design codes and suitable factors-of-safety. Except for the end segments, a minimum factor-of-safety of 1.4 is provided. The use of pressurized annular grouting to fill the space between the structural lining and the rock is common in tunnel and shaft lining applications, including the WIPP shafts. The longitudinal and transverse membranes will be made of materials that are deformable, have low permeability and high longevity, and are compatible with salt rock. These materials are commonly used as geomembranes in a wide range of long-term applications. Precast elements were selected for the AGB lining because of improved quality control relative to cast-in-place methods; the elements can be manufactured under controlled conditions. And, finally, the prototyped bulkheads to be used in AGB have previously been installed at the WIPP for other experiments.

Several parameters or considerations in the AGB design rely on numerical modeling calculations that include the creep behavior of salt. In every such calculation, the modeling methods used were those proven to best reproduce measured WIPP behavior [3]. A few of the key features of this advanced salt modeling technology are:

- The Munson-Dawson multimechanism, transient creep law as the constitutive model for salt.
- Frictional slide lines to represent the clay seams.
- A stress-state based criterion for determining the extent of a DRZ in a salt.

The calculations of flow (leakage) also represent the observations and measurements made at the WIPP during the last decade.

CONCLUDING REMARKS

Even though the best technology is believed to have been used on the design and evaluation of the AGB, risks and uncertainties can be identified. Proper engineering approaches have been applied to mitigate the design concerns, but an actual full-scale demonstration of the AGB can help resolve them.

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Figure 1. Shematic of the AGB in the WIPP satigraphy [4]

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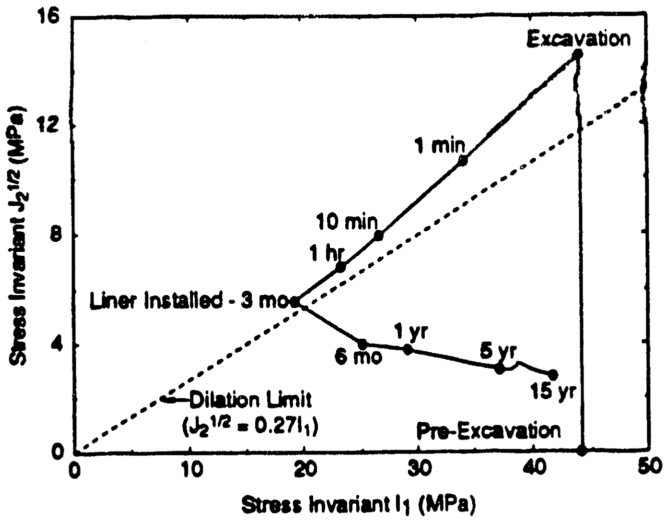
Figure 3. Stress history of salt adjacent to the center of the liner [4]

Figure 4. Liner loading with and without portal included [4]



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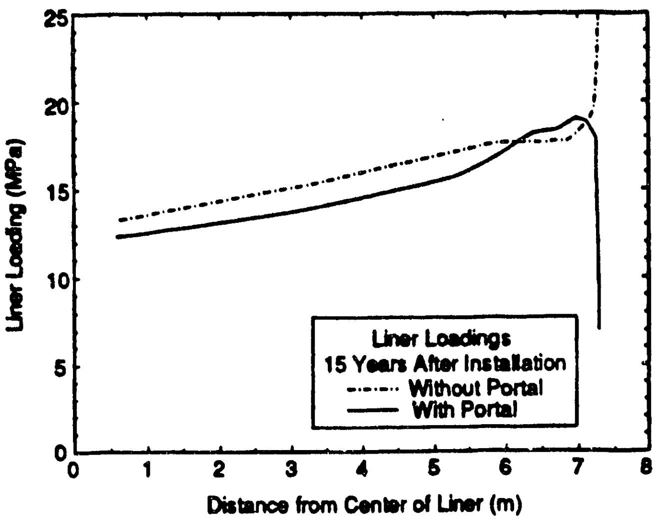

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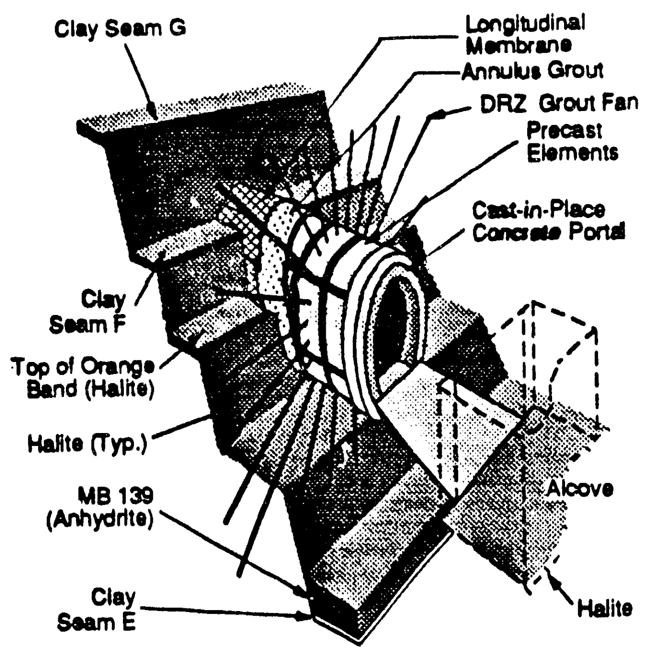

Figure 1. Schematic of the AGB in the WIPP stratigraphy [4]

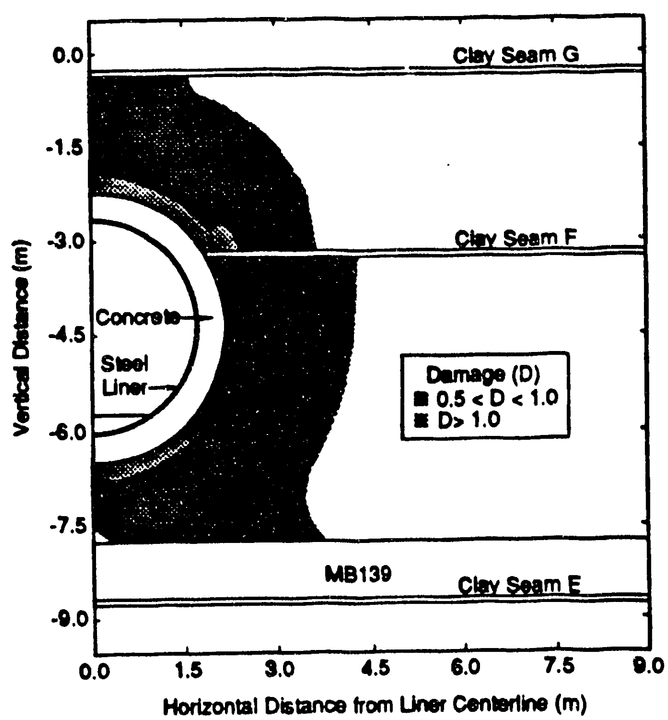

Figure 2. Damage factors before liner installation [4]

PEER REVIEW SHEET FOR WASTE ISOLATION PILOT PLANT PROJECT DOCUMENTS

SAND 92-2124C Date: 2/5/93

Title: Gas Barrier Design for the WIPP

Author(s): F. D. Hansen, M. J. Leroch, L. Van Sambeek, M. S. Lin

Type of Manuscript:

( ) SAND Report
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Sandia National Laboratories
Albuquerque, New Mexico 87185

March 17, 1993

Patrick Higgins
Experimental Programs and Waste Integration Branch
DOE WIPP Project Integration Office
Albuquerque, NM

Dear Mr. Higgins:

Attached is a copy of a conference paper entitled "Gas Barrier Design for the WIPP" (SAND92-2124C). Frank Hansen is the primary author.

This paper has been peer reviewed and has been approved by SNL line management. The abstract was approved by your office on 10/7/92.

In accordance with existing policy, I am submitting SAND92-2124C for WIPP Project Integration Office review for sensitive matter. If corrective action is required, please contact Frank Hansen.

I will assume that no reply within the stipulated three weeks indicates that you have found no sensitive matter requiring corrective action.

Sincerely yours,

Dan Garber

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