DESIGN AND CONSTRUCTION ISSUES ASSOCIATED WITH SEALING OF A REPOSITORY IN SALT

R. Cook
Westinghouse Electric Corporation
Waste Isolation Division
WIPP Project
P.O. Box 2078
Carlsbad, NM 88221

DOE/WIPP--90-030C

DE91 011481

J. Case
IT Corporation
5301 Central Avenue, N.E.
Albuquerque, NM 87108

ABSTRACT

The isolation of radioactive wastes in geologic repositories requires that man-made penetrations such as shafts, tunnels and boreholes are adequately sealed. This paper presents the current design and construction issues for sealing a repository in salt and outlines some proposed solutions. The sealing components include shaft seals, tunnel seals, panel seals, and disposal room backfill. The performance requirements and construction constraints determine the types of materials selected and their necessary properties. The current issues of interest include: 1) selection of materials for rigid bulkheads used to promote recovery of the disturbed zone permeability; 2) the selection of bulkhead geometry to "cutoff" flow through more permeable zones, or zones where recovery of the backfill properties occurs more slowly or not at all; and 3) the interaction of fluids with hazardous wastes with brine and, subsequently, with seal materials that might affect seal material longevity.

INTRODUCTION

The isolation of radioactive wastes in geologic repositories requires that man-made penetrations such as shafts, tunnels and boreholes are adequately sealed. The primary function for the seal system is to limit the release to the environment of radionuclides by their migration from the storage area. In particular, repository shafts form a potential radionuclide-migration path (14). The limitation of radionuclide migration must be achieved either by restricting groundwater flow or by retarding radionuclide migration by chemical or physical means. This paper provides an overview of the design and construction issues associated with sealing a repository in salt. The issues have been identified during studies carried out for the commercial high-level waste program (Office of Nuclear Waste Isolation) and for the Waste Isolation Pilot Plant (WIPP) Project in Carlsbad, New Mexico.

Work supported by the U.S. Department of Energy
Assistant Secretary for Defense Programs,
Office of Defense Waste and Transportation management,
under DOE Contract No. DE-AC04-86AL31950

For a nuclear waste repository, the seal system must ensure that the regulatory requirements are met with regard to limiting the release of radionuclides to the accessible environment. For a repository sited in salt strata, a primary role for the seals is to limit the flow of groundwater both into and out of the repository horizon. In the short term (less than 1000 years), groundwater flow must be limited by seal components composed of relatively impermeable, volume stable materials placed in the shafts and tunnels connecting the repository to the surface. Seal materials also provide a structural function within the sealing system. Over the long-term period, groundwater flow must be limited by the consolidation of the backfill by repository closure to form an impermeable horizon at depth.

SEAL SYSTEMS

Major elements of the overall seal system for a repository in salt will be bulkheads and backfill. Bulkheads will be emplaced in the shafts and underground facility excavations, and will be relatively impermeable rigid structures that will provide immediate barriers to the flow of fluids. At the WIPP, the bulkheads will have a design life that is sufficient to allow time for the backfill to consolidate and form an impermeable barrier in association with the natural rock. This period of time will be finite, although possibly long relative to that normally expected from engineered structures.

The rock and the consolidated backfill will be the primary long-term barrier in preventing radionuclide migration to the accessible environment. At the WIPP, backfill will be placed in all disposal areas as these are filled; backfill will also be used in access excavations, including the shafts, as the facility is decommissioned. The backfill will accelerate the formation of an impermeable barrier by filling the void spaces and reducing the amount of closure needed to reconstitute the salt. Since the backfill must be relatively stable and geochemically compatible to the host rock salt, crushed salt is a primary candidate for the seal material.

Sealing boreholes will also be important since boreholes may penetrate below the repository. Seal emplacement may vary considerably from hole to hole depending on borehole depth, location, orientation and condition. A major consideration may be the presence and condition of the borehole casing. Plugging a hole without removal of casing would produce a double interface which could be a significant preferred flow path, particularly in the long term, as the casing or grouting behind the casing deteriorates. Boreholes that reach the repository horizon should either be consumed by the shaft excavations or should be located within barrier protection pillars. An additional issue is sealing exploratory or test boreholes drilled from the shafts, or underground workings, to ensure that there are no detrimental effects on the performance of the repository system.

The performance goals for a repository seal system will be tied to the performance of the overall repository system or natural barrier system. Once the requirements of the seal system have been established, each part of the seal system can be evaluated in order to establish its contribution to overall performance. The requirements of the different seal components will relate to

Page(s) Missing

from

Original Document

Disturbed Zone

The existence of a disturbed zone about the excavations is a primary design consideration for seals. It represents a zone of increased porosity due to the development of macro- and micro-fractures resulting from stress redistribution following excavation of the openings. The zone possesses greater permeability than the undisturbed salt due to its increased porosity. Theoretical studies (10,15) and field measurements (5,8) support its existence. The disturbed zone may extend several radii from the excavation. Its existence at a location selected for a seal may provide significant flow paths unless measures are taken to mitigate this permeable zone.

The in situ permeability of salt is not well known, although values of the order of 1 nanodarcy have been obtained from testing at the WIPP site. Immediately in the vicinity of excavations, in the disturbed zone, enhanced permeability values can be anticipated. At the WIPP, predictions of the zone of increased permeability in Fig. 1 after excavation have been made using empirically scaled porosity-permeability relations developed by Lai (2), as presented in Fig. 2.

Fig. 1. Relationship of Salt Permeability Near an Excavation

Fig. 2. Modifications of Lai's Original Relationship

Fracture Healing

Fracture healing in salt depends primarily on the compressive stress across the fracture (19). Studies (12,13) demonstrate that the application of compressive stress reverses the fracture development process. The probable mechanism is a rapid localized creep of asperities in contact along a fracture interface that forms an interlocking network. Recrystallization may be a factor with fracture healing in the presence of brine. Results indicate that 70 to 80 percent of original strength can be recovered in several days, and low permeability levels can be re-established by the fracture healing process. Thus, it is possible that permeability within the disturbed zone can be reduced by reducing intercrystalline porosity, and by "healing" of fractures.

While fracture healing and the reduction in intercrystalline porosity in salt may result in recovery of the disturbed zone in salt, it is not likely that a reduction will occur in the more rigid beds that may occur in salt strata adjacent to excavations. At the WIPP, observations have confirmed the existence of a highly hydraulically conductive zone within the immediate floor of the underground facility associated with an anhydrite layer, Marker Bed 139, that develops progressively with time.

Seal Interface Zone

The seal interface zone between the rock and the seal provides a significant flowpath in sealing low permeability formations. Field testing of seal plugs

(1) has shown that the predominant flow is likely to be through the interface region with lesser contributions from the plug core, the disturbed zone, or the surrounding formation. Laboratory tests which have simulated field conditions also conclude that flow is concentrated in the interface zone. Lingle and Bush (7) have determined that plug permeabilities are primarily caused by flow at the rock/seal interface that may be 50 to 100 times greater than the in situ rock permeabilities. These results indicate the need for improving the seal performance at the interface.

Bulkhead Seal Longevity

The required design life for the bulkhead seals may be of the order of several hundred years, and will be dependent on the time for the backfill barrier to become effective. An important design issue with respect to bulkhead seals durability is the potential for brine-waste-seal interactions to affect seal degradation. Materials selection must ensure 1) that seal degradation is dependent on whether the seal is geochemically compatible with the groundwater; and 2) that the rate of water flow through the seal will not degrade it. Evaluation of brine-waste-seal interactions using chemical equilibrium analyses to estimate seal dissolution rates will be required for the design of sealing the systems.

Strength of Bulkhead Seals

The placement of the bulkhead seal provides a rock/plug structural interaction that will result in changes of the shear and normal stresses along the plug boundary and in the interface zone. The normal stresses are thought to develop uniformly over these surfaces, whereas the shear stresses develop peak values near the ends of the plug, and reduced stresses towards its center. The design should reduce the development of tensile stresses in rigid parts of bulkheads to maintain integrity of the seal system.

Materials Selection

Cementitious materials have been suggested because the technology for sealing boreholes with cementitious materials is well established in the oil industry. A large data base exists concerning their chemistry, mineralogy, and engineering properties. Construction practices are well established and a variety of emplacement techniques are available, including bulk placement, shotcreting, and precast emplacement. Materials selection is probably flexible with regard to water content, cement type, and coarse and fine aggregate to achieve the required properties (Table I), and design can be tailored to seal requirements to produce a cost effective sealing method. For example, it may be necessary to develop a mix exhibiting minimum shrinkage and workability for emplacement in shafts.

Table I. Required Properties for Cementitious Materials

BACKFILL DESIGN ISSUES

Material Selection

The crushed salt backfill can be selected and emplaced with specified properties to promote consolidation in various locations within the underground repository. The properties of interest include the particle size, particle gradation, moisture content, and porosity. The mining of salt results in a fairly consistent size distribution, although it may be appropriate to screen the run-of-mine material. It is likely that a graded material may result in more rapid consolidation than a uniformly sized material.

In general, crushed salt will be used as a backfill in the repository and in the shafts. Materials may be added to the crushed salt to reduce gas generation from the waste and fluids seeping from the rock. Earthen backfill may also be used in the shafts where insoluble materials are needed to prevent water inflow from the overlying strata. The purpose of the backfill is to limit deformations and, in the long-term, to form an impermeable monolith enclosing the waste.

Consolidation

The consolidation characteristics of crushed salt are a primary concern for backfill design. The particle size gradation, moisture content, additives and applied pressure during and following emplacement are the main considerations that can be controlled and can determine the final consolidated condition of the backfill. According to Wagner (15), crushed salt backfill in a repository without undergoing compression would not compact during a period of 25 years. However, abandoned granular waste-salt piles have been observed to harden after periods of less than one year. A possible explanation of the hardened condition is caking that results when granular salt absorbs moisture and subsequently dries out, producing a salt cement at points of grain contact Kaufman (7). In addition, glossy, rutted surfaces are observed where mine vehicles made repeated passes over backfill at one mine. These areas represent both hardening and compaction under relatively low compressive stress, together with the effects of humidity.

Crushed salt backfill consolidation will be sensitive to brine inflows from the surrounding salt formation, and it will be necessary to select an emplacement moisture content that accommodates the expected brine inflow rates. Moisture content has been found to have a significant effect on crushed salt consolidation (4).

In the shafts, it may be necessary to select an emplacement density (porosity) that accommodates the different closure rates at different depths. This would entail placement of backfill at higher densities near the top of the shaft. The need for water to enhance compaction properties is significant to recrystallization of the backfill over the long-term period.

Additives

The possible uses for additives to the backfill may include adsorption of gases generated from the waste, or brine from the rock or radionuclides. The actual additives will depend upon the particular requirements established for the backfill. To be effective, the additives will 1) need to be uniformly dispersed within the backfill; 2) be of sufficient quantity to provide the required containment; and 3) have a sufficiently large surface area. Bentonite has been proposed as a possible additive to absorb brine.

CONSTRUCTION ISSUES

Grouting

Effective grouting may be difficult to achieve in a weak material like salt. Grout pressures may be sufficient to open up new fractures as old ones are filled, and there is likely to be difficulty in pumping grout into the microfractures. Chemical grouts may more effectively seal salt; however, their longevity and chemical stability within the environment is more difficult to establish for the long term.

Backfill Emplacement in Waste Storage Area

Run of the mill salt obtained from mining operations is a prime candidate for backfill emplacement. This material will have a fairly consistent size distribution, although it may be appropriate to screen the material for emplacement. The construction methods for its emplacement would entail 1) screening of oversized pieces; 2) mechanically mixing with additives; 3) transporting by conveyor belt or pneumatic methods to the underground location; and 4) emplacement at specified densities.

Since it is probably appropriate that the mining areas and the waste storage areas are maintained administratively separate in order to isolate the areas containing radioactive materials, then consideration must be given to the transportation of the crushed salt backfill into the radioactive waste area.

For emplacement in the waste storage areas, pneumatic stowing may be used but has the disadvantage that initial compaction is not easily controlled. A possible approach might be to blow the backfill material into place to reduce the overhead space, as far as irregularities in tunnel ceilings permit, and use a coarse grout to fill void spaces. Any procedure that could expose workers to poorly ventilated spaces would have to be evaluated with regard to safety issues.

Quality Control

Quality control methods for placement of materials must establish indices to demonstrate that the seal material components have been constructed and backfill emplaced according to the design specifications. For crushed salt and earthen materials, these methods might include sieve analysis (to verify grain size distributions); in situ nuclear density and sand cone methods (to verify emplacement density); and moisture content measurements. For cementitious materials, these methods might include surveillance of mix proportions, and sieve analysis on coarse and fine aggregate, slump tests and sampling of density, and strength and deformability testing by laboratory methods to verify important design properties.

POTENTIAL DESIGN CONCEPTS

Main considerations in the design and construction of a seal system is to reduce flow along the seal interface zones and through the disturbed zone about excavations. Rock disturbance may be minimized by appropriate selection of excavation techniques for removal of disturbed zones. Conceptual designs have been advanced for keying the seal into the rock to provide a more effective barrier. These concepts will require thought to ensure that the keys do not create an enlarged disturbed zone due to the absence of support during construction.

A preferred method to treat the disturbed zone is to take advantage of the ability of the salt to heal fractures when subject to confining stress. This requires the emplacement of a structural seal that will not yield. After emplacement of such a structural seal, stresses will build up on seal components. The stresses within the disturbed zone are expected to build up to approximately 50-60 percent of the nominal lithostatic stress within a 25 year period, as illustrated in Fig. 3 (3). This will result in reduction of permeability of the disturbed zone in the salt as fractures close and heal. In the long term, stresses will continue to build up (albeit slowly) and, eventually, the disturbed zone will be diminished as the full lithostatic pressures develops.

Fig. 3. Interface Stress/Permeability Around Drift Seal

For the emplacement of bulkhead seals, it may be necessary to remove portions of the floor and roof strata and "key the seals" into the surrounding formation. To be effective, this must be completed within a short time frame in order to minimize further disturbance to the strata. The selection of a tapered plug may also reduce shearing and increase compression along the interface zone; this has been proposed by the German waste isolation program. An alternative concept to "keying the seals" was proposed by Kelsall, et al. (15), to eliminate the potential migrations of the disturbed rock zone, and to construct a narrow cutoff as a series of overlapping boreholes (Fig. 4) and grouted with a low permeability material prior to excavation of adjacent holes. In this way only a small volume of the layered salt is disturbed at any one time. The holes would penetrate through the part of the disturbed zone in which the permeability is significantly increased (i.e., the length would probably be in the range of 1 to 2 times the entry width).

Fig. 4. Concept for Forming Impermeable Barriers

In order to make predictions of the development and recovery of the permeability of the disturbed rock zone, the porosity-permeability relationship as presented by Lai (2) has been used to construct an empirical relationship assuming that the undisturbed salt intrinsic permeability is approximately 1 nanodarcy at a porosity of 0.1 percent (8), as shown in Fig. 2. The relationships provide a basis for evaluating the performance of the disturbed zone surrounding for a combination seal system comprised of backfill, and two rigid bulkheads using analytical methods presented by Kelsall, et al. (16); more recent stress-strain data for crushed salt consolidation has been presented by Holcomb and Shields (6). The results of a preliminary analysis are presented in Fig. 5 and indicate 1) a rapid recovery of the disturbed rock zone permeability surrounding rigid bulkheads within 25 to 50 years; and 2) a less rapid recovery of this zone surrounding crushed salt backfill.

Fig. 5. Effective Permeability of Panel and Seal System

CONCLUSIONS

The design issues discussed in this paper include 1) the selection of materials for rigid bulkheads used to promote reduction of the disturbed zone permeability; 2) the selection of bulkhead geometry to "cutoff" flow through more permeable zones, or zones where recovery of the backfill properties occurs more slowly or not at all; and 3) the interaction of fluids with hazardous wastes with brine and, subsequently, with seal materials that might affect seal material longevity.

Seal design requirements, including both performance requirements and construction constraints, determine the types of materials selected and their necessary properties. The materials used within a particular seal system will constrain both the design and the construction method. The types of materials presently under consideration for application to seal construction include crushed salt and salt compressed into blocks, cementitious materials, and earthen materials.

Seal design concepts developed from different programs have been discussed in this paper. These concepts rely on careful excavation techniques, the emplacement of rigid seals to allow recovery of the surrounding disturbed zone, and removal of disturbed zones where recompression is not likely to reduce permeability.

REFERENCES

1. C. L. CHRISTENSEN AND E. W. PETERSON, "The Bell Canyon Test Summary Report," SAND80-1375, Sandia National Laboratories, Albuquerque, New Mexico (1981).

2. C. S. LAI, "Fluid Flow Through Rock Salt Under Various Stress States," Ph. D. Dissertation, Michigan State University, East Lansing, Michigan (1971).

3. DOE, Design Validation Final Report, U.S. Department of Energy DOE/WIPP 86-010 prepared by Bechtel.

4. DOE, "Interim Geotechnical Field Data Report," U.S. Department of Energy Report, DOE/WIPP 86-012, prepared by Bechtel National, Inc. for the U.S. Department of Energy, San Francisco, California (1986).

5. D. J. BORNS AND J. C. STORMONT, "An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone," SAND87-1375, Sandia National Laboratories (1988).

6. D. J. HOLCOMB AND M. SHIELDS, "Hydrostatic Creep Consolidation of Crushed Salt with Added Water, SAND87-1990, Sandia National Laboratories, Albuquerque, NM, (1987).

7. D. W. KAUFMAN, "Salt Specialities, in Sodium Chloride, The Production and Properties and Properties of Salt and Brine," American Chemical Society Monograph Series, pp 275-281 (1960).

8. E. PETERSON, P. LAGUS, J. BROWN, AND K. LIE, "WIPP Horizon In Situ Permeability Measurements Final Report," SAND85-7166, Sandia National Laboratories (1985).

9. EPA (U.S. ENVIRONMENTAL PROTECTION AGENCY), "Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Code of Federal Regulations, Protection of Environment, Title 40, Part 191, U.S. Government Printing Office, Washington, D.C. (1986).

10. J. B. CASE AND P. C. KELSALL, "Coupled Processes in Repository Sealing," Proceedings of the Symposium on Coupled Processes Associated with Nuclear Waste Repositories, Academic Press, Inc., New York, pp. 591-604 (1987).

11. J. C. STORMONT, "Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant," SAND87-3083, Sandia National Laboratories (1988).

12. J. L. WITHIAM, M. G. SMITH, J. B. CASE, AND P. C. KELSALL, Laboratory Investigation of Crushed Salt Consolidation and Fracture Healing, Report submitted to the Office of Nuclear Waste Isolation (ONWI), IT Corporation, Albuquerque, NM (1984).

13. L. S. COSTIN AND W. R. WAWERSIK, "Creep Healing of Fractures in Rock Salt," SAND80-0392, Sandia National Laboratories, Albuquerque, NM (1980).

14. M. NATARAJA, J. PESHEL, AND J. J. K. DAEMEN, "Design, Construction and Performance Considerations for Shafts for High-Level Waste Repositories," Shaft Engineering, Institution of Mining and Metallurgy (1989).

15. P. C. KELSALL, J. B. CASE, AND C. R. CHABANNES, "A Preliminary Evaluation of the Rock Mass Disturbance Resulting From Shaft, Tunnel or Borehole Excavation," ONWI-411, Columbus Ohio (1982).

16. P. C. KELSALL, J. B. CASE, W. E. COONS, R. D. ELLISON, AND D. MEYER, "Schematic Designs for Penetration Seals for a Repository in the Permian Basin - Architect-Engineer Turnover Package," Report Prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus Ohio (1984).

17. R. LINGLE AND D. D. BUSH, Full Scale Borehole Sealing Test in Basalt Under Simulated Downhole Conditions, TRE-82-09, Report Prepared By Terra Tek Engineering for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio (1982).

18. R. A. WAGNER, "Preliminary Investigation of the Thermal and Structural Influence of Crushed Salt Backfill on Repository Disposal Rooms," ONWI-138, Office of Nuclear Waste Isolation, Battelle Memorial Institute (1980).

19. STONE AND WEBSTER ENGINEERING CORPORATION, "A Preliminary Assessment of the Healing of Fractures in Salt," ONWI-363, Columbus Ohio (1983).

1c00091

Table I

Required Material Properties for Cementitious Materials

Shrinkage or volumetric expansion
Workability
Heat of hydration
Strength (tensile and compressive)
Deformational properties (elastic plastic and long-term creep)
Volumetric and thermal stability
Hydraulic conductivity
Durability
Thermal properties
Seal dissolution rates

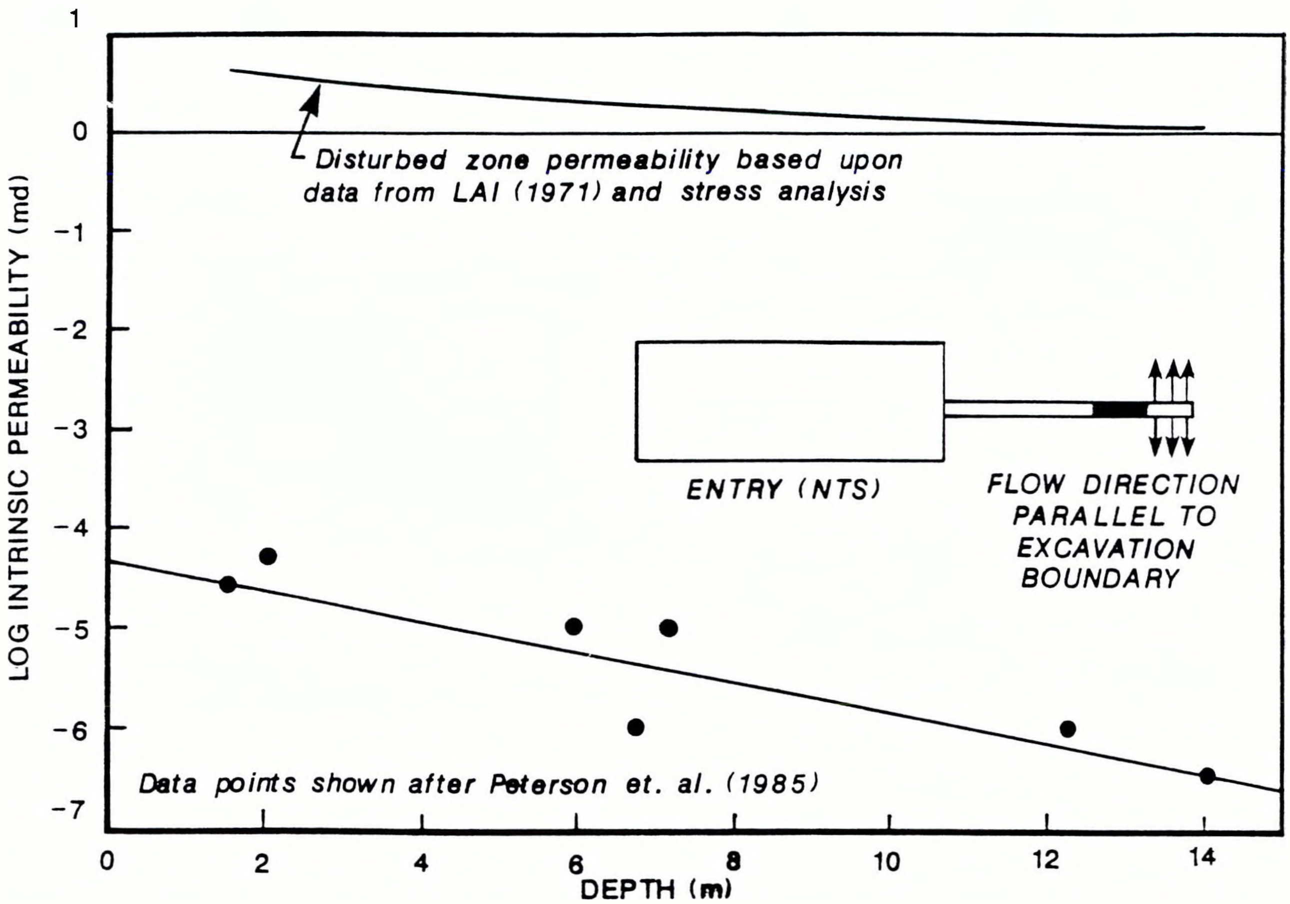

Fig. 1. Relationship of Salt Permeability With Depth Near an Excavation

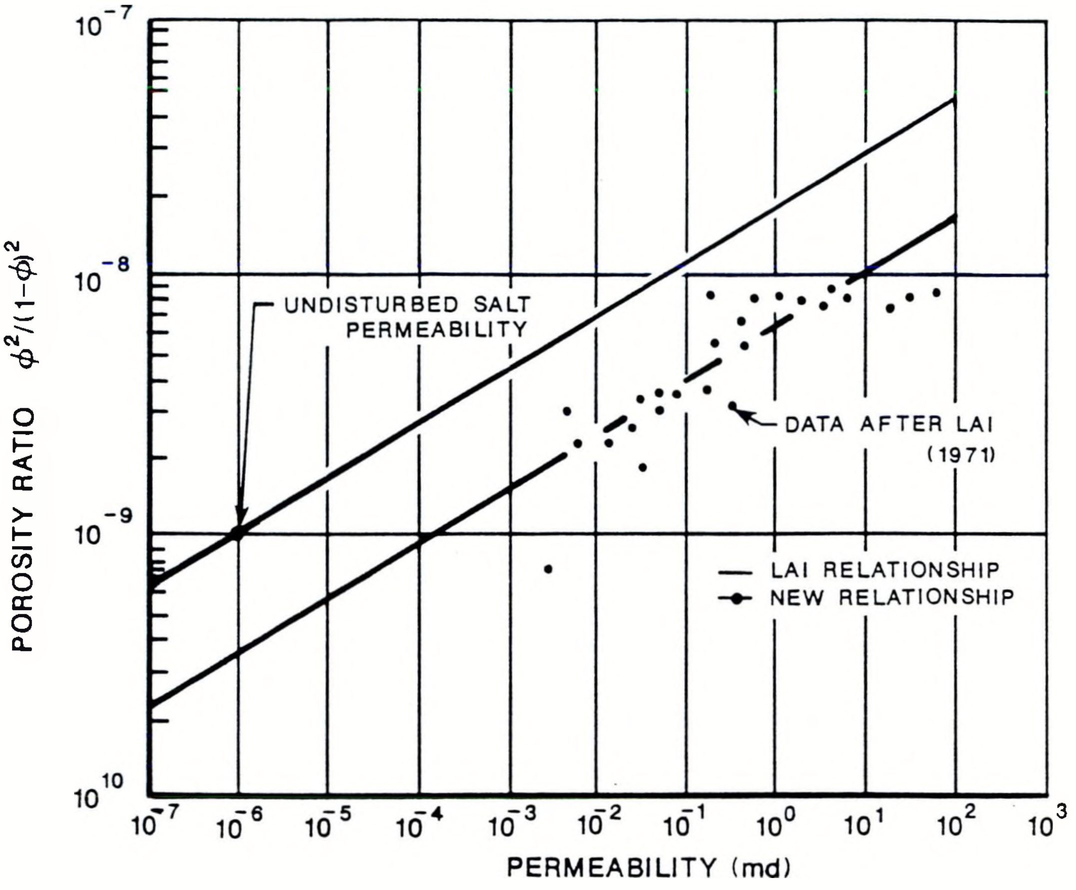

Fig. 2. Modification of LAI's Original Relationship

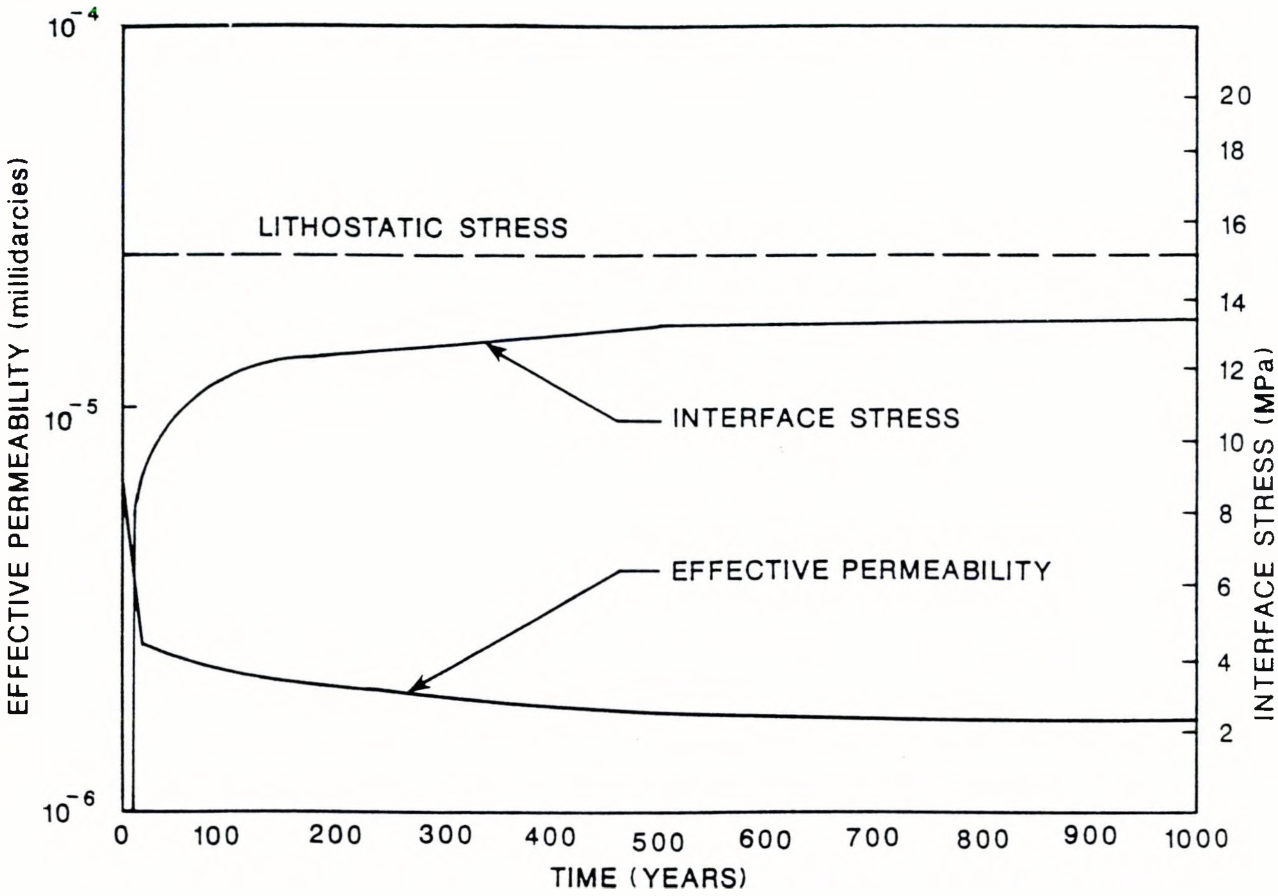

Fig. 3. Interface Stress and Effective Permeability of DRZ Around a Concrete Plug — Panel Access Drift Seal

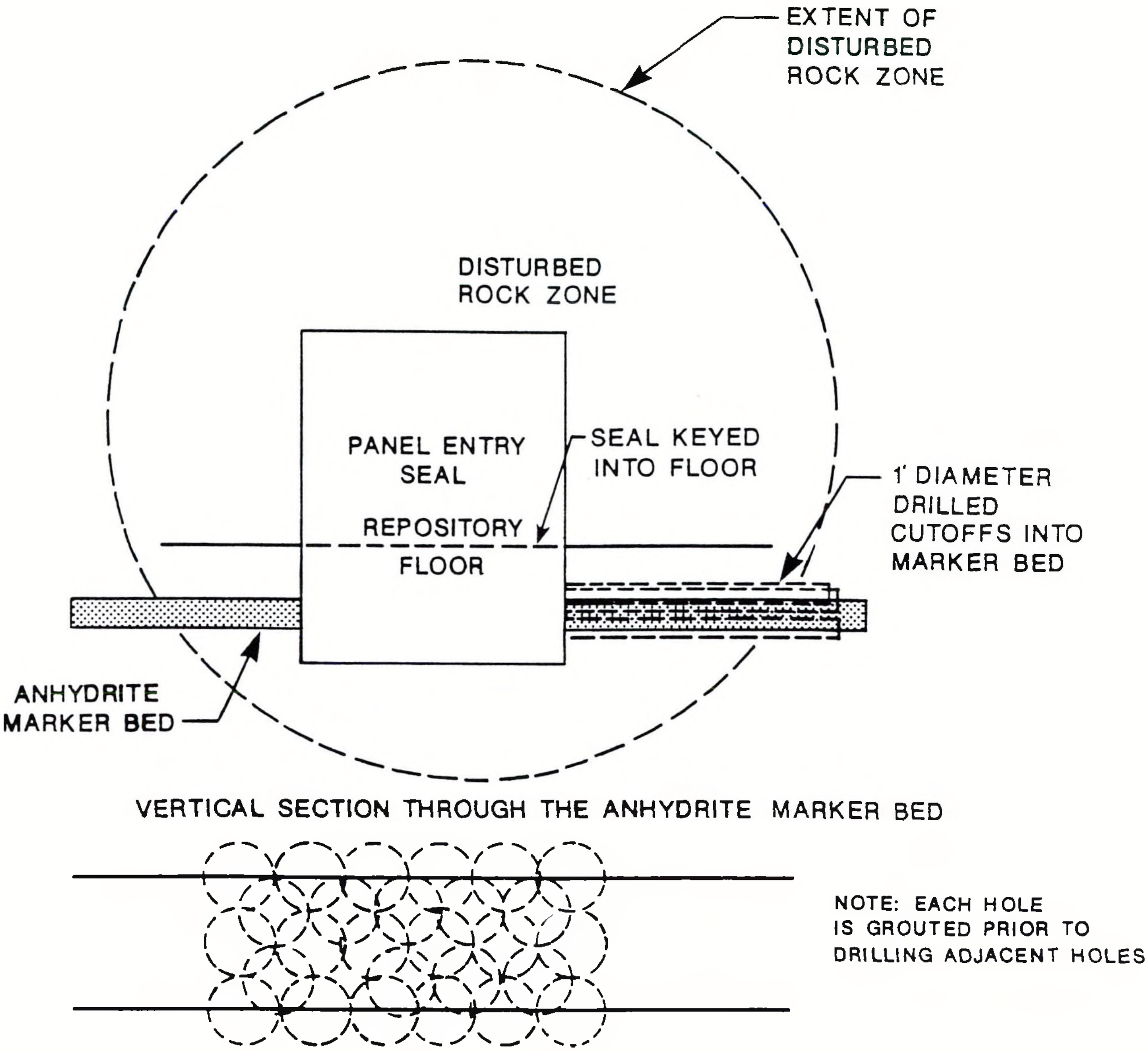

Fig. 4. Concept for Forming Impermeable Barriers in the Adjacent Marker Bed Using Overlapping Holes

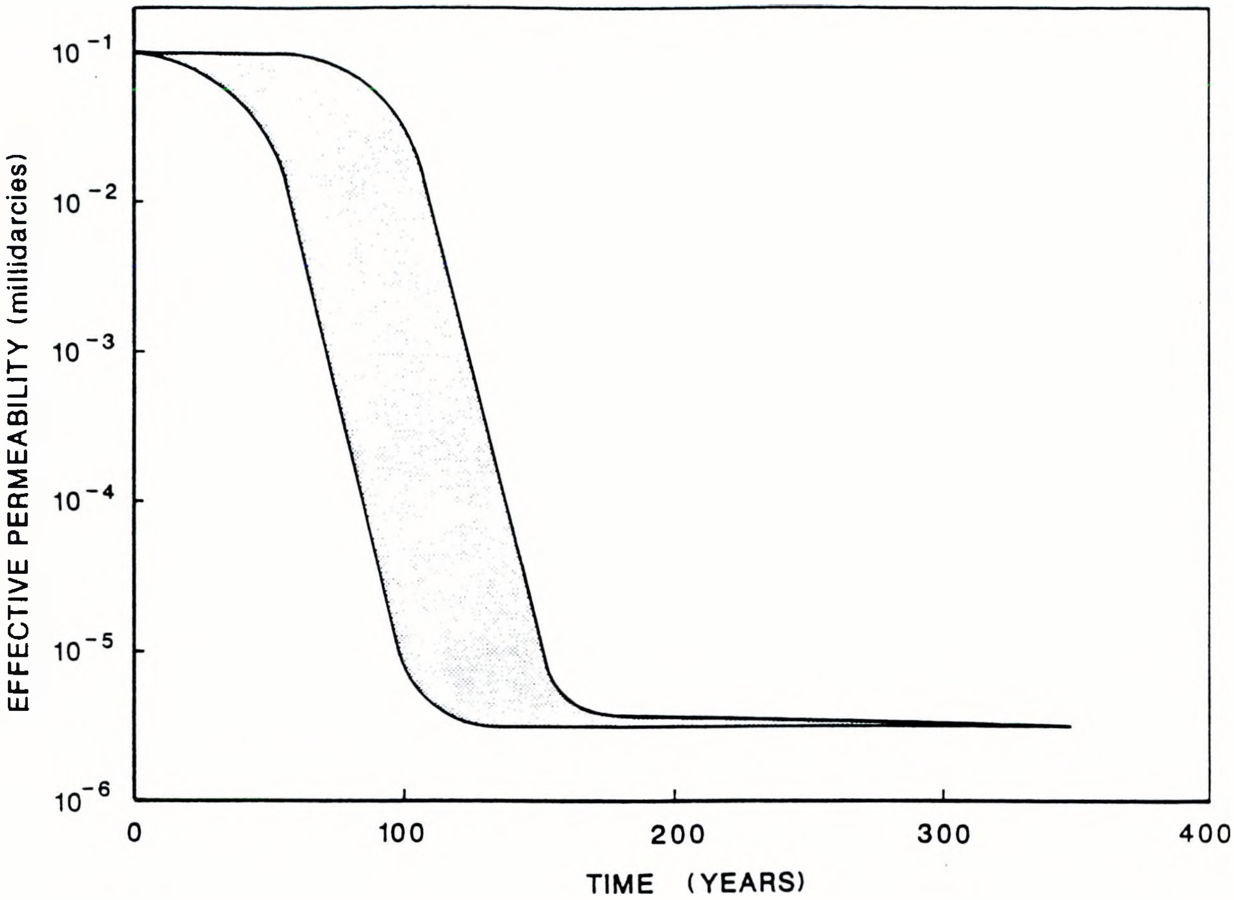

Fig. 5. Effective Permeability of a Panel Access Drift Seal System