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EVALUATION OF PROPOSED PANEL CLOSURE MODIFICATIONS AT WIPP

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Environmental Evaluation Group
New Mexico

December 2001

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December 2001

FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment of New Mexico. The WIPP Project, located in southeastern New Mexico, became operational in March 1999 for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U. S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, and the National Defense Authorization Act for Fiscal Year 2000, Public Law 106-65, continued the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the compliance of the generator sites with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts associated with WIPP. Another important function of EEG is the independent on- and off-site environmental monitoring of radioactivity in air, water, and soil.

Matthew K. Silva
Director

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ACKNOWLEDGMENTS

The EEG authors wish to thank Dr. John Abel and Dr. Rusty Morgan for their technical assistance on this project and timely review of the draft report. Also thanks to Ms. Jill Shortencarier for final word processing and compilation of the report and Ms. Linda Kennedy for the final edit and references check.

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ACRONYMS

AAR	Alkali aggregate reactivity
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

A key component in the design of the WIPP repository is the installation of concrete structures as panel seals in the intake and exhaust drifts after a panel has been filled with waste containers. As noted in the EPA final rule, the panel seal closure system is intended to block brine flow between the waste panels at the WIPP. On April 17, 2001, the DOE proposed seven modifications to the EPA concerning the design of the panel closure system.

EPA approval of these modifications is necessary since the details of the panel design are specified in EPA's final rule as a condition for WIPP certification. However, the EPA has not determined whether a rulemaking would be required for these proposed design modifications. On September 4, 2001, the DOE withdrew the request, noting that it would be resubmitted on a future date.

The Environmental Evaluation Group (EEG) contracted with two engineers, Dr. John Abel and Dr. Rusty Morgan, to evaluate the proposed modifications. The EEG has accepted the conclusions and recommendations from these two experts: 1) replacement of Salado Mass Concrete with a generic salt-based concrete; 2) replacement of the explosion wall with a construction wall; 3) replacement of freshwater grouting with salt-based grouting; 4) option to allow surface or underground mixing; and 5) option to allow up to one year for completion of closure. The proposed modification to allow local carbonate river rock as aggregate is acceptable pending demonstration that no problems will exist in the resulting concrete. The proposed modification to give the contractor discretion in removal of steel forms is not supported. Instead, several recommendations are made to specifically reduce the number of forms left, thereby reducing potential migration pathways.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Project, located in Southeastern New Mexico has been constructed by the U.S. Department of Energy (DOE) to provide permanent disposal of long-lived transuranic (TRU) waste from the U.S. defense activities and programs. The facility must comply with 40 CFR 191, Subpart A during the period when radioactive waste are being emplaced (operating period) and with 40 CFR 191, Subpart B and 40 CFR 194 for long-term disposal. The U.S. Environmental Protection Agency (EPA) concluded that WIPP met the requirements of 40 CFR 191 and 194 and made a Certification Decision in May 1998 (EPA 1998). The repository began receiving radioactive TRU wastes in March 1999.

The underground WIPP facility design includes eight panels for disposing of transuranic waste (see Figure 1). At the present time waste is being emplaced in Panel 1 and excavation of Panel 2 has been completed. Each panel includes seven waste disposal rooms as well as a ventilation intake drift and a ventilation exhaust drift.

A key component in the design of the WIPP repository is the installation of concrete structures as panel seals in the intake and exhaust drifts after a panel has been filled with waste containers. The panel seals are required to rectify the damage done to the natural formation by excavation and are, at best, an imperfect attempt to recapture the characteristics of the original rock (Silva and Chaturvedi 1995). As noted in the EPA final rule, the panel seal closure system is intended to block brine flow between the waste panels at the WIPP. The DOE application (DOE 1996a) identified four design options. As a specific condition of compliance, the EPA mandated the use of Option D. But the agency also determined that the use of a Salado Mass Concrete – using brine rather than fresh water – would produce concrete seal permeabilities in the repository more consistent with the values used in the DOE performance assessment (EPA 1998, 27355).

In an April 17, 2001 letter from Dr. Inés Triay to Mr. Frank Marcinowski of EPA (Appendix A), the Carlsbad Field Office (CBFO) of the DOE proposed several panel closure design

WIPP Facility and Stratigraphic Sequence

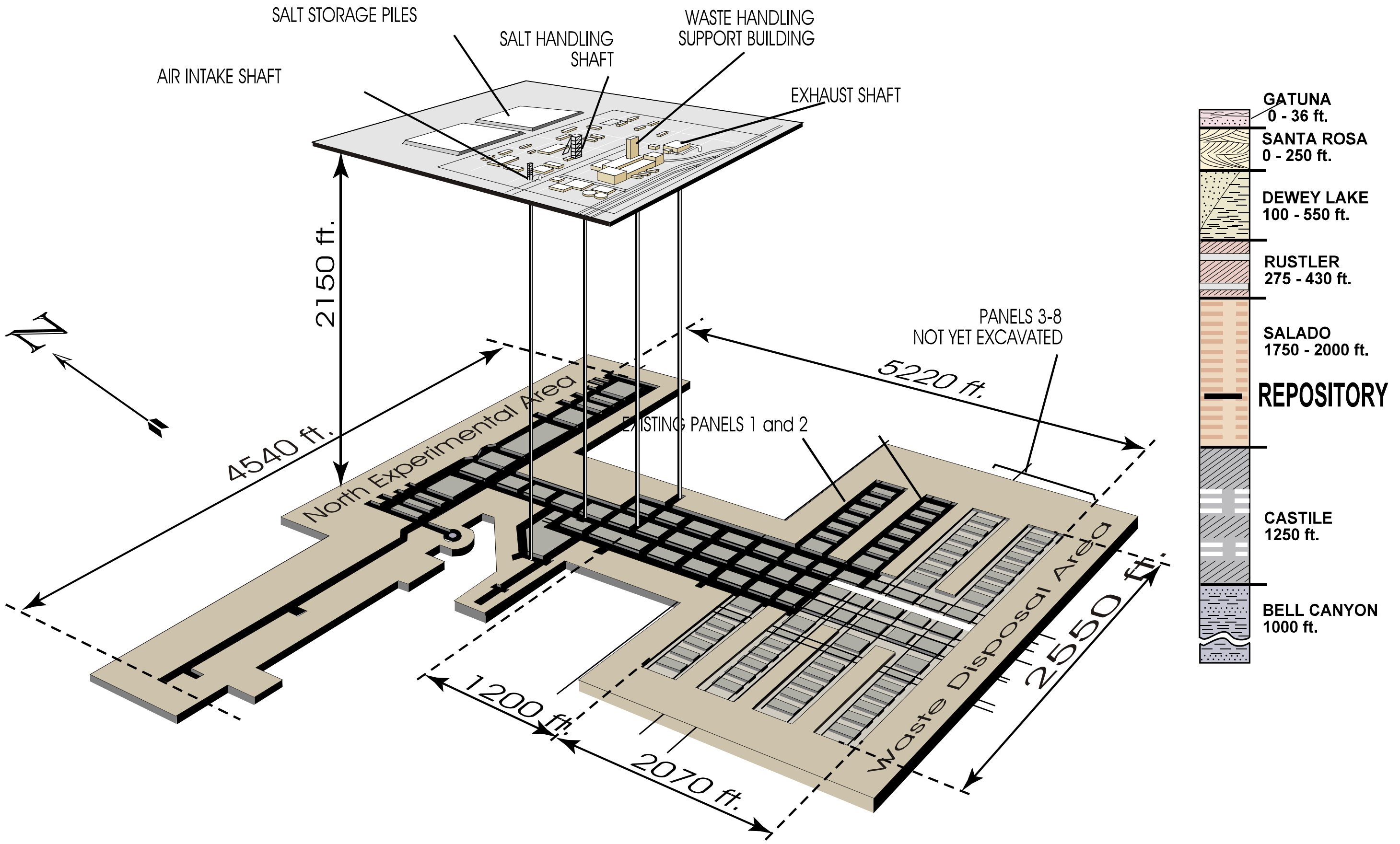

Figure 1. The WIPP facility and stratigraphic sequence. Panel 1 is currently in use. The mining of Panel 2 was completed on October 13, 2000. SOURCE: DOE, 2000.

modifications. EPA approval of the changes proposed by DOE is required since the details of the panel designs are specified in EPA's final rule as a condition for WIPP certification (EPA 1998, 27355). The EPA final rule allows for a modification to the design of the facility. Significant modification requires a rulemaking in accordance with the WIPP compliance criteria (40 CFR §§ 194.65-66). [1]

The Environmental Evaluation Group (EEG), in its role of providing technical evaluations on the design, construction, and operation of the WIPP Project, contracted with two engineers that are expert in relevant aspects of panel seal design and construction to evaluate these proposed enhancements. Dr. John F. Abel, Jr., a Mining Engineer from Golden, Colorado, evaluated the proposed enhancements concentrating on bulkhead and masonry wall stability. Dr. D. R. Morgan, a Materials Engineer from Vancouver, B.C., Canada, evaluated three of the proposed enhancements: (a) changes in proposed aggregate; (b) change to a salt-based grout; and (c) change in mass concrete requirements. The reports of Dr. Abel and Dr. Morgan are included as Appendices B and C to this report. The EEG has accepted the conclusion and recommendations contained in these two reports as summarized below.

The proposed enhancements were subsequently withdrawn from consideration by DOE in Dr. Triay's letter to Mr. Marcinowski, dated September 4, 2001 (Appendix D). This letter indicated that the topic was expected to be revisited at some time in the future. Toward this end, and because of the time spent in evaluation of the proposed modifications, EEG decided to proceed with this report on the proposed modfications.

2.0 PROPOSED PANEL CLOSURE DESIGN MODIFICATIONS

The proposed enhancements are discussed in the order used in Dr. Triay's letter of April 17, 2001. More details can be obtained from the appended reports.

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[1] The EPA has not yet published an opinion as to whether or not the changes proposed by DOE constitute a modification.

2.1 Replace Salado Mass Concrete with a Generic Salt-based Concrete

This proposed enhancement is acceptable and probably preferable since it gives the Contractor more flexibility and responsibility in meeting performance-based objectives. However, in order to ensure adequate performance, the project specification should be written in rigorous performance-based specification language. In addition, more detail should be provided in the specification regarding permissible constituent materials for the mass concrete components such as salt and shrinkage compensating materials.

It is appropriate that the Contractor be supplied with pertinent information regarding specifications for Salado Mass Concrete. This information can provide the Contractor with a starting point for generic salt-based mixture proportioning. However, the responsibility for concrete performance would reside with the Contractor.

2.2 Replace the Explosion Wall with a Construction Wall

This proposed enhancement is acceptable. The analysis in Dr. Abel's report indicates that the 12-foot thick explosion-isolation masonry wall is not needed. The panel closure bulkhead will adequately protect against the design basis 480 psi methane explosion which cannot occur prior to (at least) 15 years after panel closure. The strength of the 4-foot thick construction-isolation masonry walls is sufficient to protect against the design pressure generated by a roof fall within the panel.

2.3 Replace Freshwater Grouting with Salt-based Grouting

EEG agrees with the proposal to replace the freshwater grout with a salt-based grout since it will counteract the tendency for dissolution (and hence void formation) of fresh water based grouts. This is apparently only a point for clarification. The design report detailing the original panel closure options (DOE 1996), specifies that if the Salado Mass Concrete is used instead of a fresh water/plain cement concrete, the contractor shall use a salt saturated grout. This would be the case for any salt-based concrete.

2.4 Option to Allow Local Carbonate River Rock Aggregate in Lieu of Crushed Quartz

It may be possible to demonstrate that this option is acceptable. However, Dr. Morgan raised three concerns. One concern is that the coefficient of thermal expansion of the aggregate influences the coefficient of expansion of the concrete containing such aggregate. Dr. Morgan states, “Serious differences in the coefficients of thermal expansion have been reported to occur with aggregates with very low expansion, such as certain granites, limestones, and marbles.” Therefore, it will be necessary to demonstrate that this is not a problem with the proposed local carbonate river rock.

A second concern is that naturally rounded gravels used in concrete production are better if they have a certain “crush-count”. Dr. Morgan states, “There are certain advantages to having partially fractured faces in a sufficient percentage of the aggregate particles, including enhanced compressive, flexural and tensile strength development in the concrete made with such particles, compared to concrete made with natural rounded particles only.” Consideration should be given to using aggregate with a partial crush-count if this option is chosen.

A final concern is that some carbonate aggregate is chemically reactive, resulting in deleterious expansion of the concrete. Therefore, an evaluation of the alkali aggregate reactivity (AAR) susceptibility should be conducted.

2.5 Option to Allow Surface or Underground Mixing

This proposed enhancement is acceptable. Dr. Abel concluded that either surface or underground mixing was adequate, provided the critical time between mixing and placement in the form is met. It may be easier to meet the time limitation by underground mixing. In fact, as with Proposed Enhancement I (replacement of Salado Mass Concrete with a generic salt-based concrete), it gives the contractor more flexibility and responsibility in meeting performance based objectives.

2.6 Option to Allow Steel Forms to be Left in Place or Removed

This option is more complicated than the title implies because it also would allow the contractor the flexibility to modify the design of the bulkhead. Abel's analysis of the current design and his recommendations should be seriously considered. The current four cell design with the steel forms remaining is inferior to a monolithic single cell because there are many more potential leakage flow paths through the bulkhead. However, the size of these bulkheads exceeds that of known continuous pours. Abel recommends the following approach for dealing with this dilemma:

It is recommended that the panel bulkhead specifications:
1) provide an incentive for the contractor to minimize the number of cells (preferably to one).
2) require that each cell be filled as a continuous monolithic concrete pour,
3) require the contractor support the fluid concrete in all cells with external structures,
4) require the contractor to remove the support structures and forms between internal cells,
5) provide for a rough form surface between internal cell walls (possibly with a layer of burlap),
6) assure that some grout points are located at the roof concrete/rock salt contact and
7) prevent the use of all internal form spacer supports.

2.7 Option to Allow up to One-year for Completion of Closure in Lieu of 180 Days

This option is acceptable. Significant gas generation concentrations take much longer than one year to occur and it is preferable to do the construction properly without the pressure of an artificial deadline.

3.0 CONCLUSIONS

Of the seven proposed modifications, the EEG readily accepts five: 1) replacement of Salado Mass Concrete with a generic salt-based concrete, 2) replacement of the explosion wall with a construction wall, 3) replacement of freshwater grouting with salt-based grouting, 4) option to allow surface or underground mixing, and 5) option to allow up to one-year for completion of closure. The proposed modification to allow local carbonate river rock is acceptable pending demonstration that no problems will exist in the resulting concrete. The proposed modification to give the contractor discretion in removal of steel forms is not supported by the EEG. Instead, the EEG has proposed a number of recommendations to specifically reduce the number of forms which are left, thereby reducing potential migration pathways.

REFERENCES

40 CFR 191 Subpart A. 2001. Environmental standards for management and storage. Title 40, Protection of environment; Chapter I, Environmental Protection Agency; Code of Federal Regulations. Washington (DC): National Archives and Records Administration.

40 CFR 191 Subpart B. 2001. Environmental standards for disposal. Title 40, Protection of environment; Chapter I, Environmental Protection Agency; Code of Federal Regulations. Washington (DC): National Archives and Records Administration.

40 CFR 194. 2001. Criteria for the certification and recertification of the Waste Isolation Pilot Plant's compliance regulations. Title 40, Protection of environment; Chapter I, Environmental Protection Agency; Code of Federal Regulations. Washington (DC): National Archives and Records Administration.

Silva, Matthew; Chaturvedi, Lokesh. 1995. Need for engineered barriers at the Waste Isolation Pilot Plant. In Transactions of the American Nuclear Society, October 29- November 2, 1995. La Grange Park (IL): American Nuclear Society, TANSAO 73:123-124.

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[EPA] US Environmental Protection Agency. 1998 May 18. Criteria for the certification and recertification of the Waste Isolation Pilot Plant's compliance with 40 CFR 191 disposal regulations: certification decision; final rule. Federal Register 63(5):27354-27406.

APPENDICES

APPENDIX A

April 17, 2001 letter, Triay to Marcinowski

Department of Energy
Carlsbad Area Office
P. O. Box 3090
Carlsbad, New Mexico 88221

April 17, 2001

RECEIVED
APR 24 2001
ENVIRONMENTAL EVALUATION GROUP

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

Dear Mr. Marcinowski:

This purpose of this letter is to inform the Environmental Protection Agency (EPA), per the requirements of the Title 40 CFR Part 194 Final Rule, Supplementary Information, Section VIII.A.1.(b), regarding minor enhancements proposed to the panel closure construction specifications for the Waste Isolation Pilot Plant (WIPP) repository. As you are aware, the purpose of the panel closures is for the hazardous waste disposal unit closure and to control potential volatile organic compound (VOC) releases during waste management operations.

Secondarily, in terms of long-term performance, the Compliance Certification Application and the EPA final rule note that the closure system will also influence fluid connections between waste panels. The present panel closure design, as required in the EPA final rule, is extremely conservative (restricting VOC releases to levels that are more than two orders of magnitude less than the applicable standard). We previously briefed your agency regarding this subject on April 13, 2000 in Washington, DC and on December 12, 2000 in Carlsbad, NM.

The enhancements were identified during our continuing evaluation of engineering issues associated with operating the WIPP. The identified improvements include the following:

- Replace Salado Mass Concrete with a generic salt-based concrete
- Replace the Explosion Wall with a Construction Wall
- Replace freshwater grouting with salt-based grouting
- Option to allow local carbonate river rock aggregate in lieu of crushed quartz
- Option to allow surface- or underground-mixing
- Option to allow steel forms to be left in place or removed
- Option to allow up to one-year for completion of closure in lieu of 180-days

CBFO:ORC:DDM:SJJ:01-0753:UFC:5486

The enclosed package contains a detailed description of the enhancements and our analysis of their effects. Included also are edited versions of the technical specifications for the panel closures which incorporate the enhancements. Our analysis demonstrates that these enhancements are clearly minor, will not compromise the performance of the closures, and do not impact long-term compliance. However, we believe that implementation of these enhancements would allow construction flexibility which will increase worker safety and greatly improve the constructibility of the panel closures and better ensure the closures perform as required.

If you or your staff have any questions regarding this matter, please contact Daryl Mercer at (505) 234-7452.

Sincerely,

Inés Triay

Dr. Inés R. Triay, Manager
Carlsbad Field Office

Enclosure: Panel Closure Enhancements

cc w/ enclosure:
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S. Ghose, EPA-ORIA
C. Byrum, EPA-ORIA
N. Stone, EPA, Region VI
M. Silva, EEG
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F. Hansen, SNL

cc w/o enclosure:
S. Hunt, DOE/CBFO
H. Johnson, DOE/CBFO

CBFO:ORC:DDM:SJJ:01-0753:UFC:5486

APPENDIX B

Review of Panel Closure Bulkhead Enhancements, Waste Isolation Pilot Plant

John F. Abel

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REVIEW OF PANEL CLOSURE BULKHEAD ENHANCEMENTS

WASTE ISOLATION PILOT PLANT (WIPP)

Report to

Mr. Mark Levin
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by

John F. Abel, Jr.
Mining Engineer
Colorado P.E. 5642

July 18, 2001

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EXECUTIVE SUMMARY

As indicated on Table 1, the strength of the 4,000 psi plain concrete panel closure bulkheads (Figure 1) is sufficient to resist the 480 psi design pressure from the postulated methane explosion, during and after the planned 35-year life of the facility. The strength of the 4-ft thick construction-isolation masonry walls is sufficient to isolate the panel closure bulkhead construction areas from the design pressure generated by a panel room roof fall. The 12-ft thick explosion-isolation masonry wall, (2,500 psi) solid concrete blocks (3,500 psi) mortared with cement (2,500 psi) and hitched 6-in into the adjacent rock salt, designed for the Intake Drift and the Exhaust Drift is insufficient to resist the 480 psi methane explosion pressure (Figure 2). There is no apparent reason for an explosion-isolation wall during the six-month or one year construction of the panel closure bulkheads. Methane concentration will not increase until panel ventilation is stopped, which should only start when construction starts on the isolation walls (Figure 3).

The "Panel Closure Enhancements" refer to the main panel closure bulkheads as "The concrete monolith ---". Water retaining bulkheads (Figure 4) are normally designed and constructed as monolithic, i.e. continuous, pours without cold joints or interior form walls. The planned four cell panel closure bulkhead construction will not provide a uniform massive bulkhead but will contain three interior steel form walls. Even if a way is found to remove the three interior steel form walls, after the concrete has set in each cell, a smooth surfaced cold joint will still be present between cells. In order of declining potential effectiveness, the following panel closure bulkhead construction modifications should decrease the bulkhead leakage potential,

1) constructing truly monolithic panel closure bulkheads or
2) externally supporting the bulkhead cell forms, i.e. eliminating the form spacers, or
3) reducing the number of cells.

The size of these bulkheads, approximately 990 cu yds for the 36-ft thick Intake Drift and approximately 565 cu yd for the 26-ft thick Exhaust Drift, exceeds known continuous monolithic bulkhead pours. The Jackpot Mine west decline tapered bulkhead, approximately 20.4-ft wide by 15.5-ft high by 25-ft thick, involved only 311 cu yds of monolithic concrete pour. At West Driefontein Mine four approximately 350 cu yd monolithic sand/cement plugs were constructed in twenty days, during a mine flooding emergency.

Penetrations through a water retaining bulkhead are normally minimized, whenever possible, because they represent potential leakage flow paths through bulkheads. Essential penetrations, such as a bypass pipe, include waterstops to assure no leakage along the penetrations. The forms are externally braced. The planned 4 cell panel closure bulkhead (Figure 1) includes the use of longitudinal 1-in diameter form spacers, which also support the form wall until the concrete sets. Figure 5 indicates 55 form spacer penetrations across Cell #2 and Cell #3. Figure 6 indicates 22 form spacer penetrations across Cell #1 and Cell #4. Multiple potential flow paths are apparent across the individual cells and the steel plate and angle forms provide multiple potential connections between form spacers in adjacent cells.

The forms for water impoundment bulkheads are typically constructed of timber posts hitched into the roof and floor and braced externally by pipe columns to floor, wall and roof anchors for temporary support of the fresh concrete during construction. This would eliminate the form spacer bars. However, the bulkhead volumes will probably require at least one internal cold joint. An airtight panel closure seal may be difficult to achieve, by any method, but more so with multiple bulkhead penetrations.

The panel closure bulkheads would be classed as tapered two-way pressure bulkheads, i.e. to resist equal pressure from either side. Tapered water retaining bulkheads are typically installed to increase the shear resistance of a low-strength rock from a hydrostatic pressure acting in only one direction. If the panel closure bulkheads are airtight, closure within the panel rooms could potentially increase to 100 psi on the waste side of the bulkheads 35 years after construction (Figure 7). The two-way taper of the panel closure bulkheads was apparently designed to permit the safe excavation of the disturbed rock zones (DRZ) above and below the intake and exhaust drifts.

The strength of the concrete is critical to the strength of the panel closure bulkheads. The aggregate strength is a minor concrete strength factor which can be compensated for, if necessary, by increasing the cement in the mix. In addition, carbonate aggregate concrete probably has a lower coefficient of thermal expansion than quartz aggregate. Figure 8 indicates that concrete with quartz aggregate has a higher coefficient of expansion (approximately 6.6 millionths per °F) than either limestone aggregate concrete (approximately 3.8 millionths per °F) or dolomite aggregate concrete (approximately 5.3 millionths per °F).

Table 1. Bulkhead stability for Intake Drift (20-ft by 13-ft) and Exhaust Drift (14-ft by 12-ft)

Bulkhead or Barrier Location	Bulkhead or Barrier Type	Bulkhead Thickness (ft)	Pressure Gradient FS	Concrete/ Masonry Shear FS	Rock Salt Shear FS	Worst-Case Bending Stress FS	Best-Case Bending Stress FS
Intake Drift	Plain Concrete Bulkhead	36 31.3[1]	2.40	2.40	5.50	3.61	8.55
Exhaust Drift	Plain Concrete Bulkhead	26 21.3[1]	1.54	2.92	1.75	3.85	5.24
Intake Drift	Masonry Explosion-Isolation	12	1.03	0.63	6.37[2]	0.32	0.75
Exhaust Drift	Masonry Explosion-Isolation	12	1.03	0.77	7.68[2]	0.65	0.88
Intake Drift	Masonry Construction-Isolation[3]	4	>2300	>1450	14.6[2]	44.7	>190

Notes: [1] - Sloping face of waste disposal (pressure) side of plain concrete barrier does not provide rock salt shear resistance from the force developed by 480 psi factored design explosion pressure applied to barrier face. The rock salt shear path was therefore reduced. The bond strength between the concrete and the rock salt was conservatively assumed to be negligible. [2] - Hitched 6 inches into roof, ribs and floor rock salt. [3] - Pressure from roof fall in central part of nearest panel room.

Figure 1. Exhaust drift longitudinal cross section through panel closure bulkhead

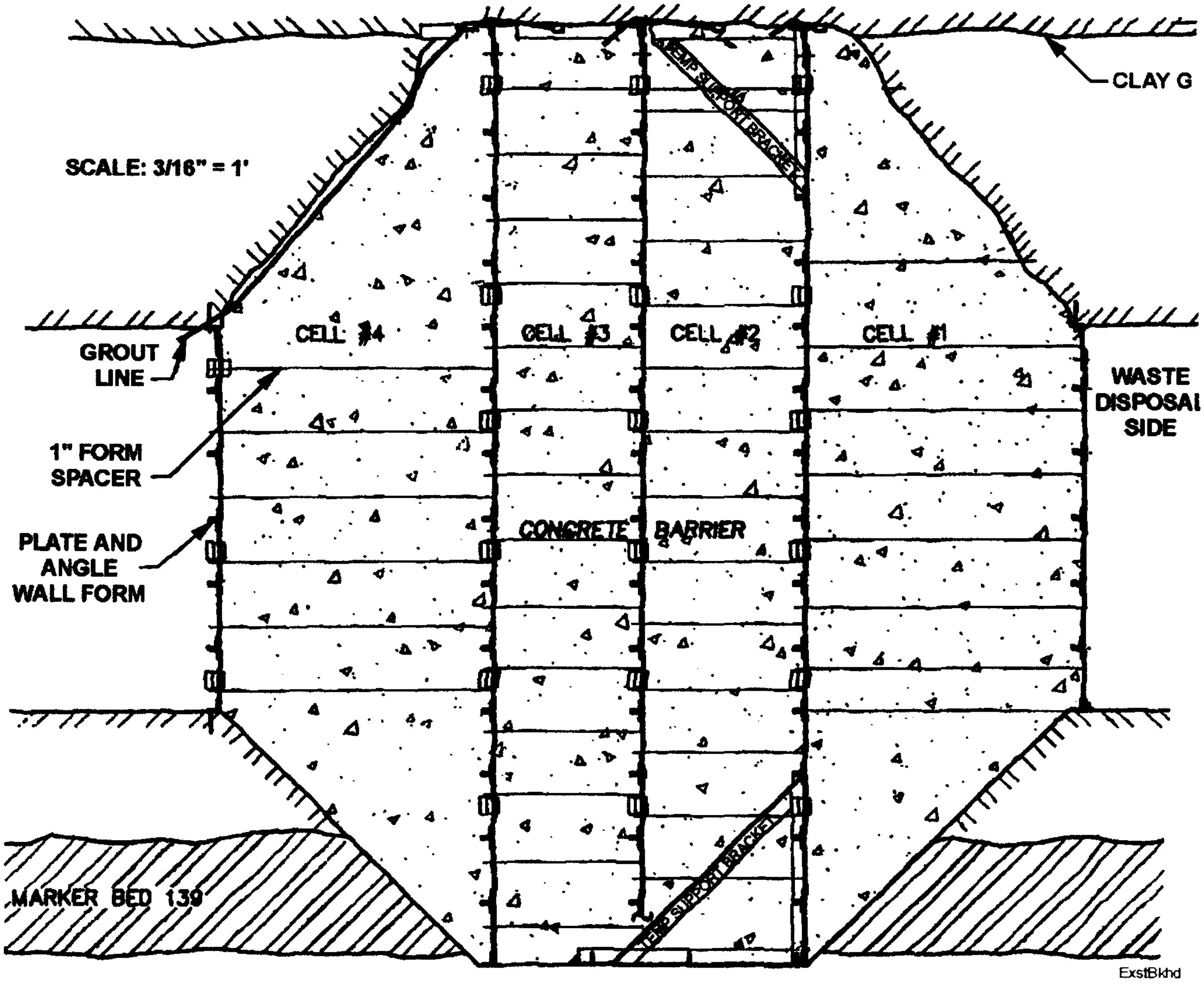


Figure 2. Explosion-isolation masonry wall bulkhead

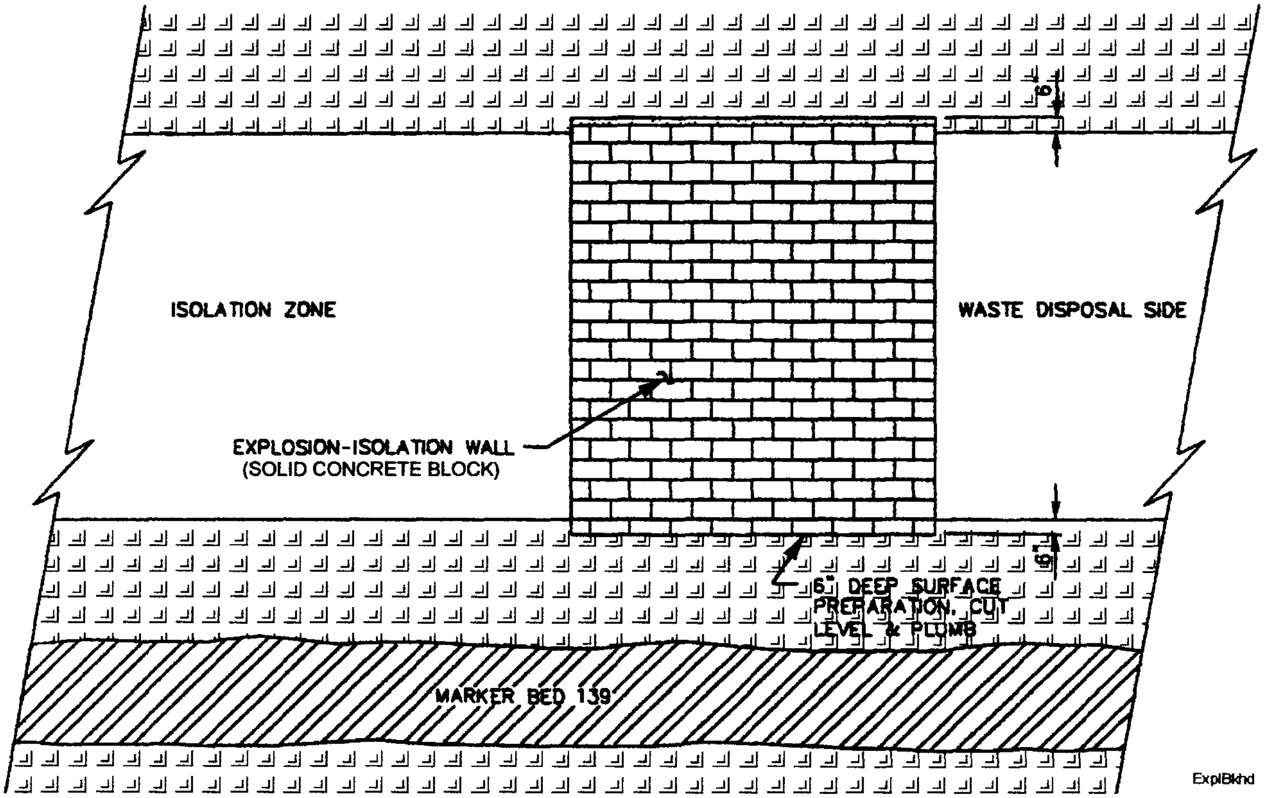
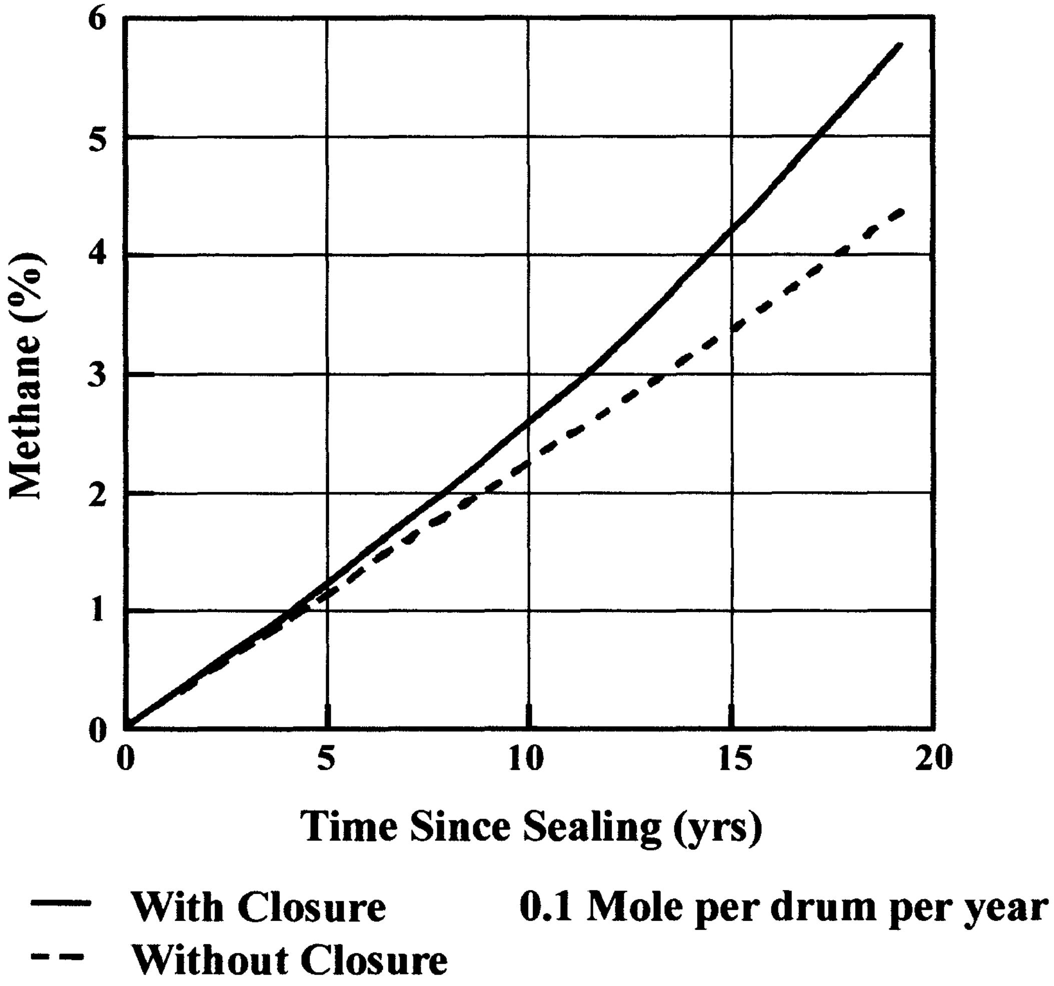


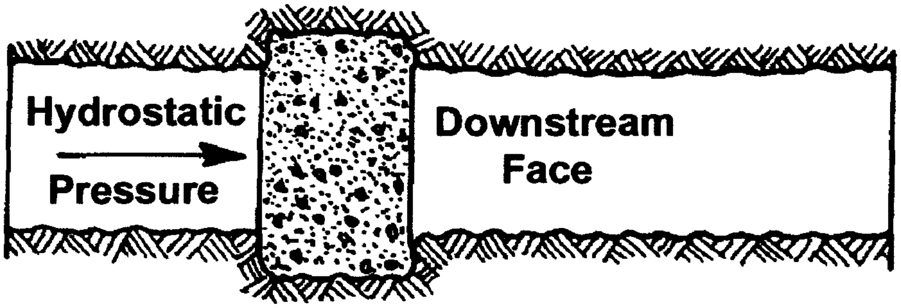
Figure 3. Methane concentration in waste panel over time



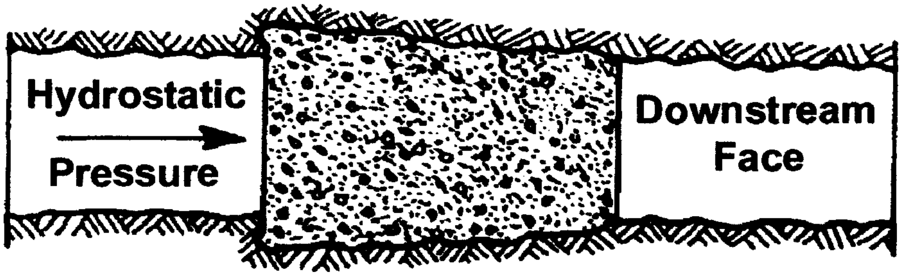
Methane concentration in waste panel over time
(modified from Dykes, et. al., 1997)

MthnTime

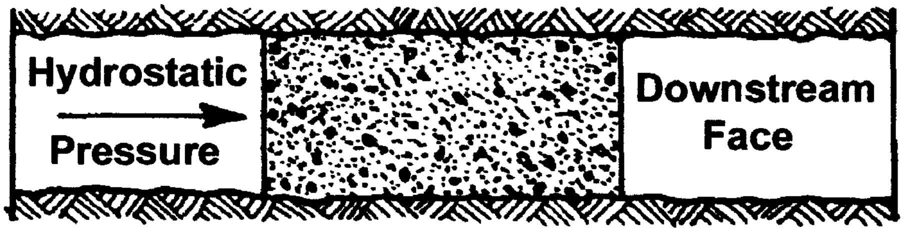
Figure 4. Water impoundment bulkhead types



Slab keyed into walls



Taper plug



Parallel plug

(Adapted from Garrett & Campbell Pitt, 1958) Blkhtyps

Figure 5. Intake drift lateral cross section through center of closure bulkhead

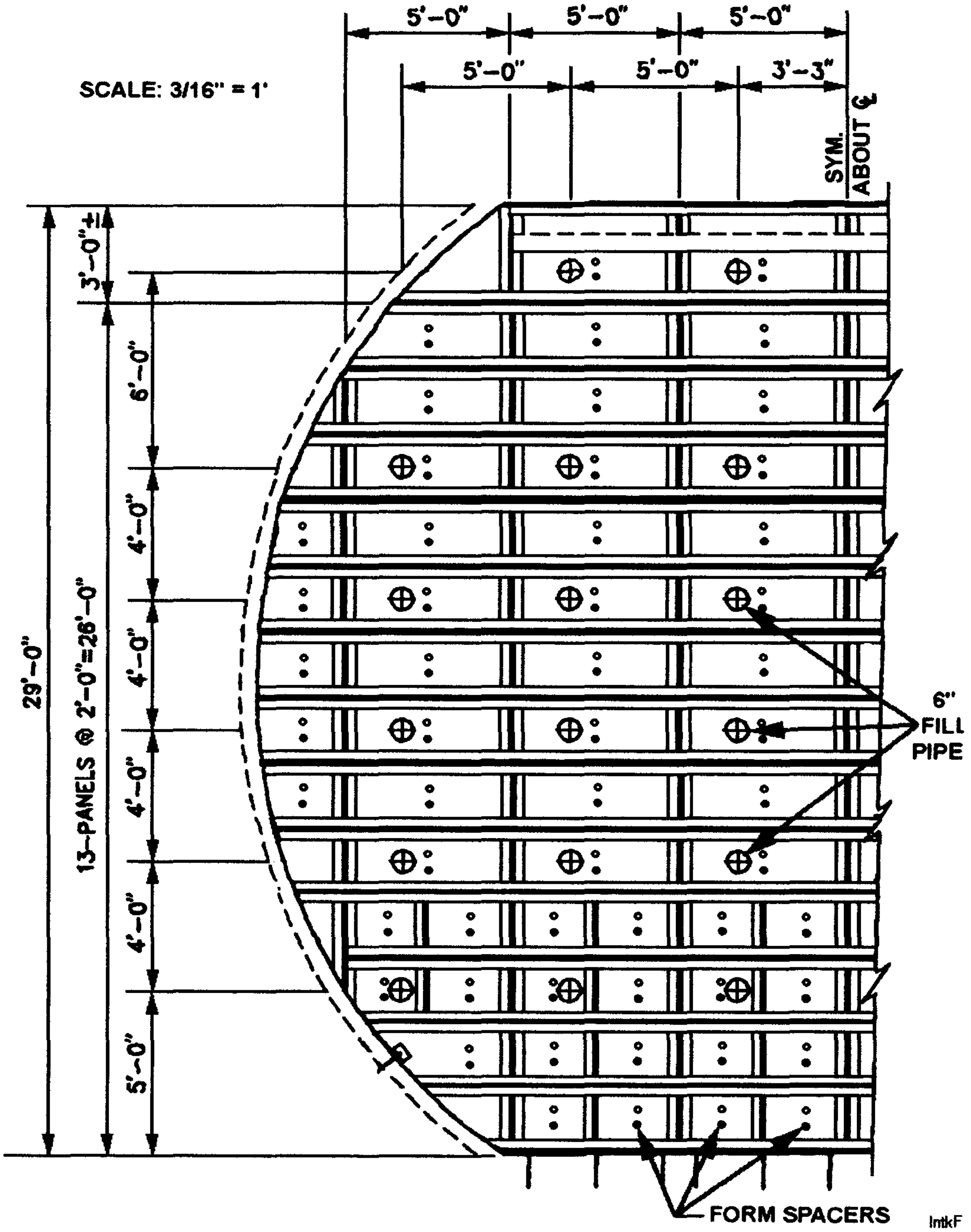


Figure 6. Intake drift lateral cross section inside panel closure bulkhead face

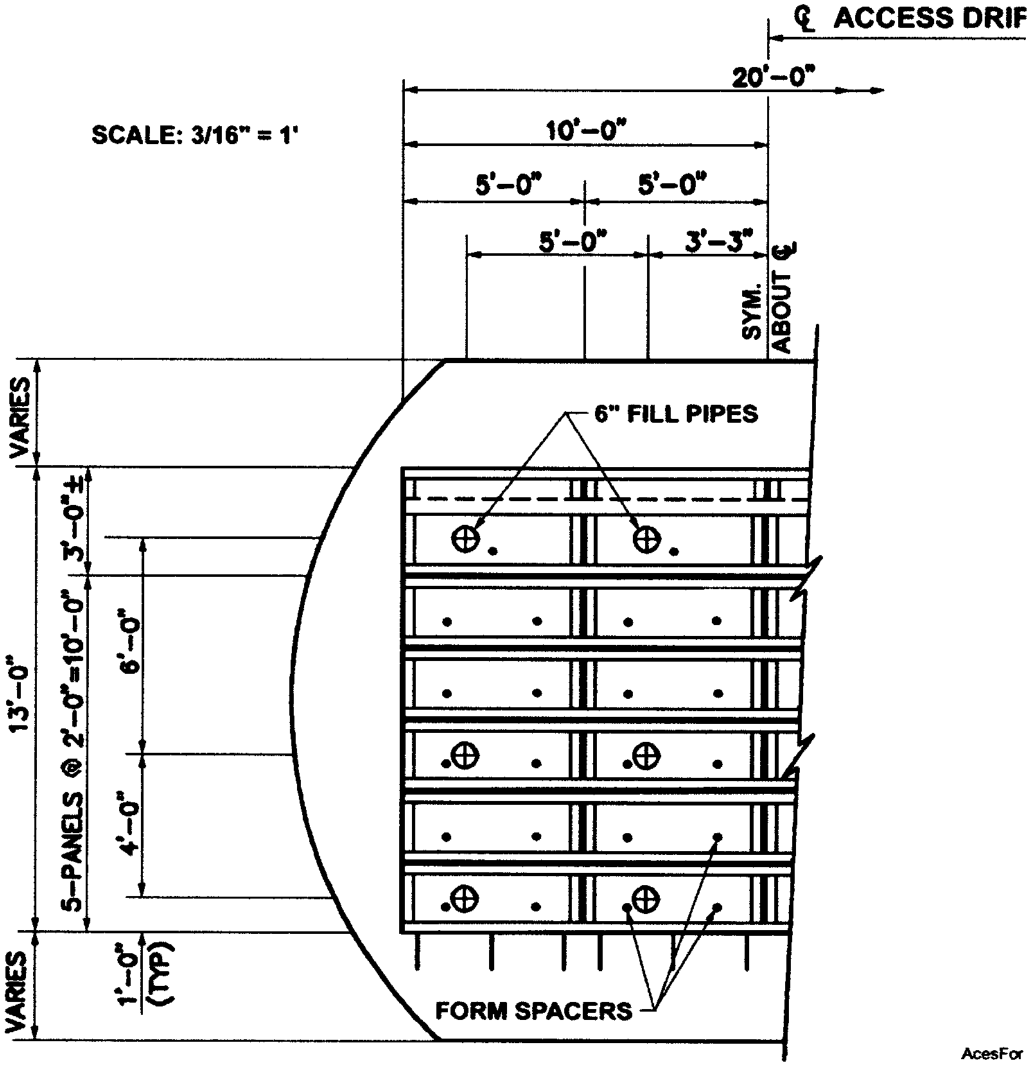
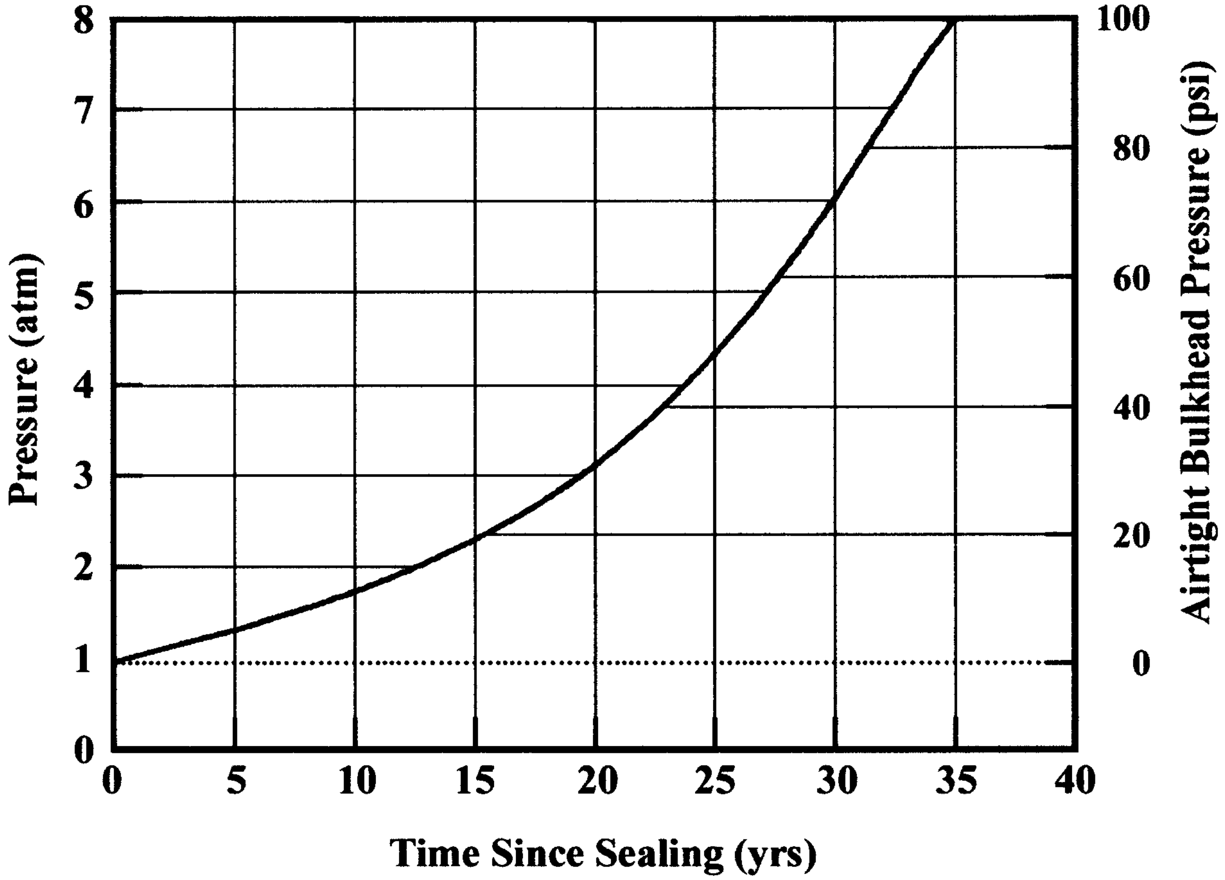


Figure 7. Pressure buildup from panel closure after panel closure bulkhead construction



Pressure buildup in a panel after closure

(modified from Dykes, et. al., 1997)

PanlPres

Figure 8. Thermal coefficients of expansion of neat cements, mortars and concretes

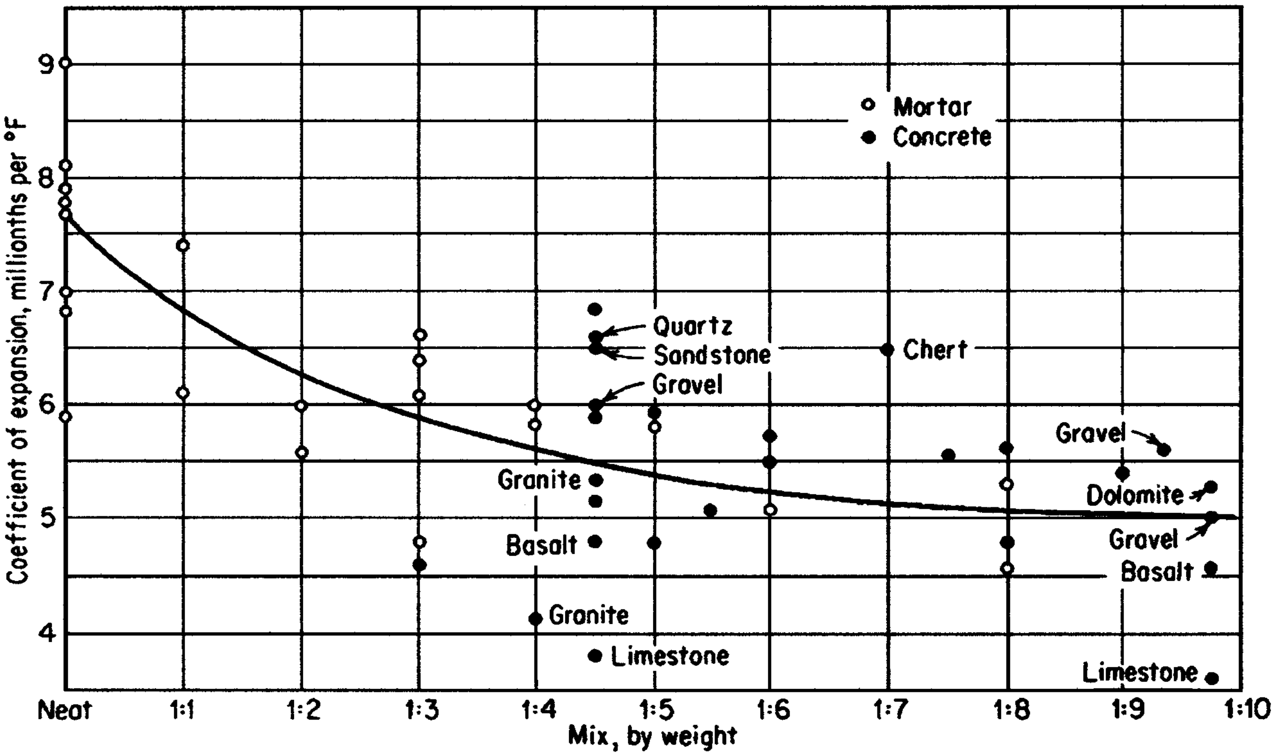


Fig. 12.8. Thermal coefficients of expansion of neat cements, mortars, and concretes. (*From U.S. Bureau of Reclamation* [106].)

TempExpn

INTRODUCTION

This report was prepared as directed by Matthew K. Silva of the Environmental Evaluation Group and Mark Levin of Mining and Environmental Services LLC for the purpose of reviewing the proposed Panel Closure Enhancements to the panel closure system area bulkheads and isolation walls, shown on Figure 9. The original optional designs for the panel closure systems are presented on Figure 10. The proposed enhancements to the Panel Closure System are described in the Compliance Certification Application (CCA). This review is specifically directed at evaluating the ability of the enhanced panel closure bulkheads and walls to provide an equivalent, or improved, panel closure. The specific enhancements proposed and reviewed are:

1) replacing the 12-ft thick explosion-isolation wall with the 4-ft construction-isolation wall,

2) allowing the use of a generic salt-based concrete in lieu of Salado-based concrete,

3) allowing the use of local carbonate river rock aggregate in lieu of crushed quartz aggregate,

4) allowing either surface or underground mixing of the concrete,

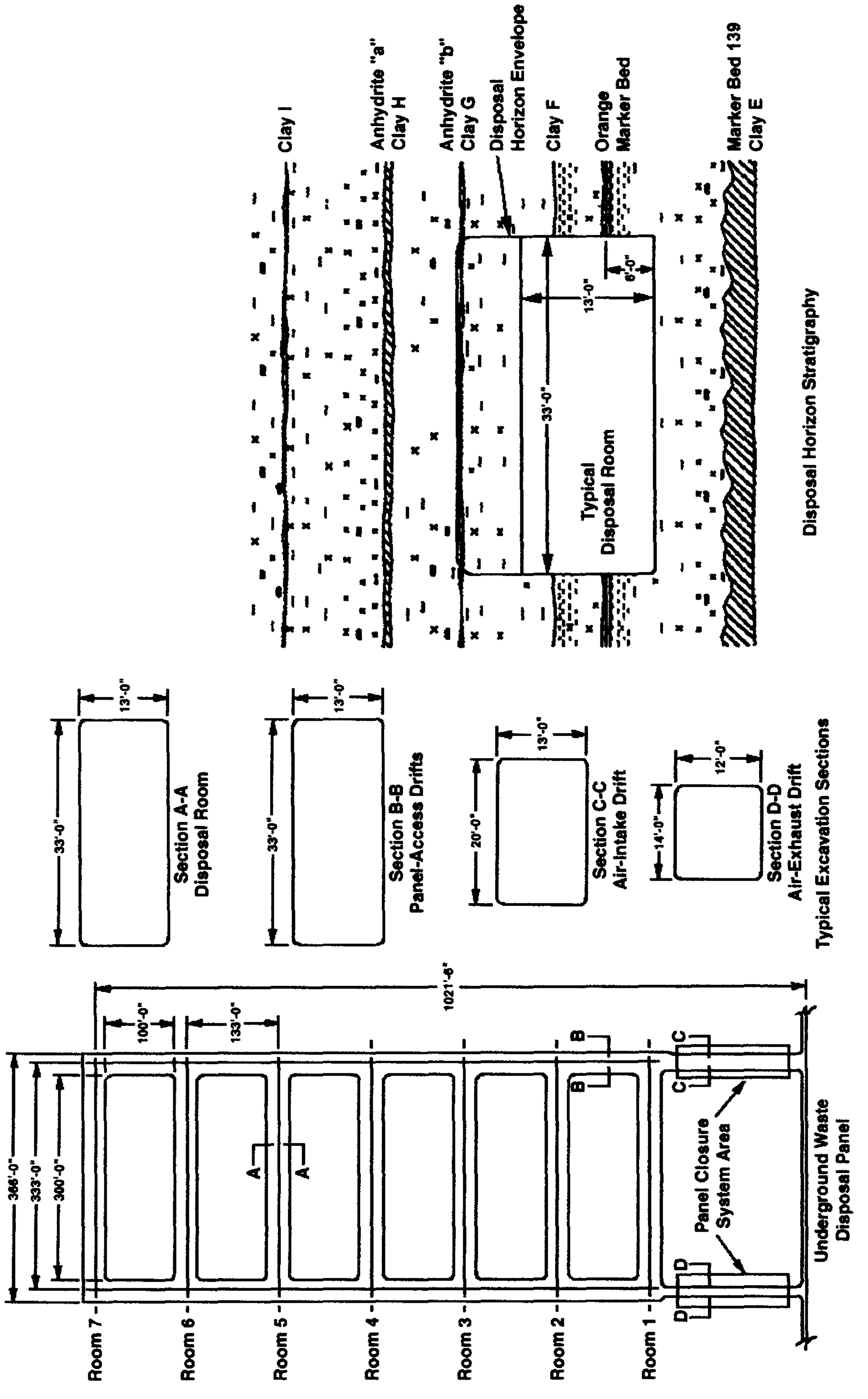
5) allowing flexibility in the bulkhead forming practices,

6) replacing freshwater grout with salt-based grout and

7) extending the construction period from 180 days to up to one year.

Item 1) relates to the necessity for and ability of the 12-ft thick explosion-isolation masonry wall to protect the workers constructing the panel bulkheads from the design methane explosion pressure. Items 2), 3), 4), 6) and 7) relate primarily to the resulting strength of the concrete in the panel closure bulkheads, over the minimum operational period of 35 years. Item 5) relates to the ability of the resulting flexibly formed panel closure bulkheads to resist both short term methane explosion pressure and long term panel closure-induced gas pressure and to prevent long term brine flow from the panels.

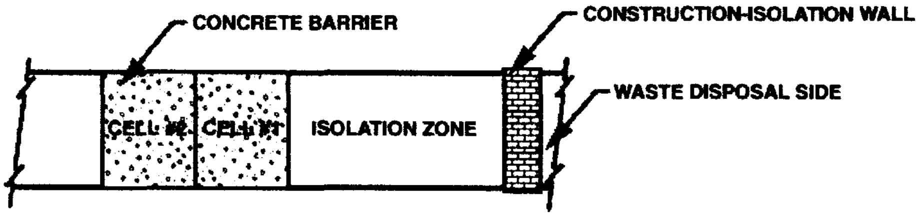
Figure 9. Location of panel closure system areas



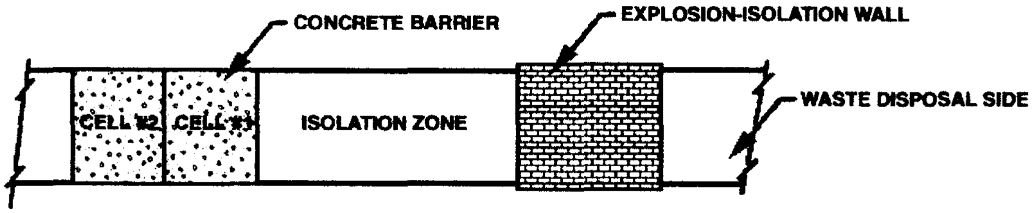
Note: Figure is not to scale. All dimensions shown are nominal.

Location of panel closure system areas (from DOE/WIPP-96-2150)

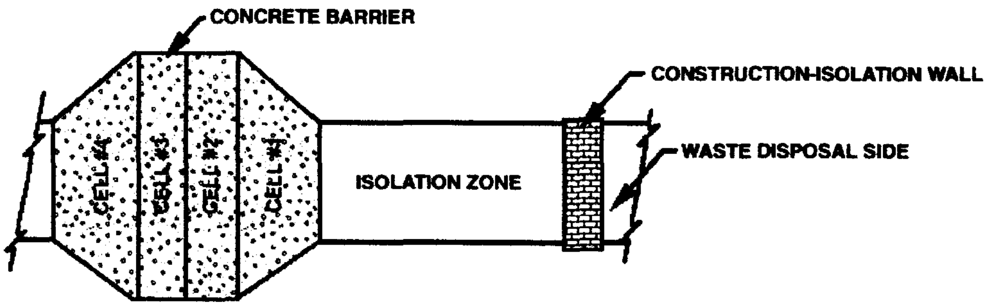
Figure 10. Optional designs for panel closure systems



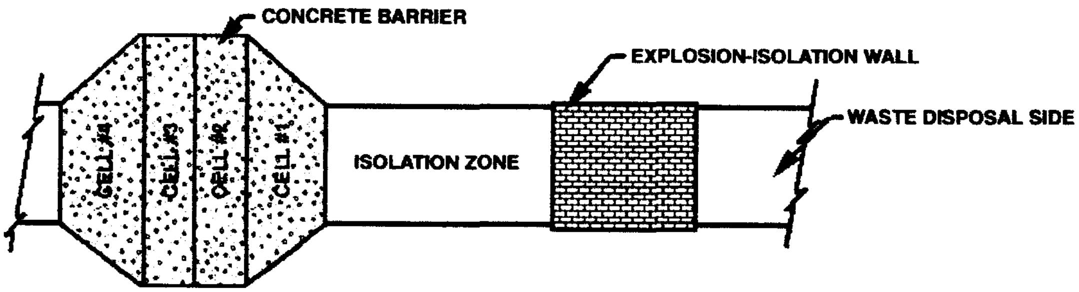
A. CONCRETE BARRIER WITHOUT DRZ REMOVED AND CONSTRUCTION-ISOLATION WALL



B. CONCRETE BARRIER WITHOUT DRZ REMOVED AND EXPLOSION-ISOLATION WALL



C. CONCRETE BARRIER WITH DRZ REMOVED AND CONSTRUCTION-ISOLATION WALL



D. CONCRETE BARRIER WITH DRZ REMOVED AND EXPLOSION-ISOLATION WALL

Optional designs for panel closure systems

(modified from DOE/WIPP-96-2150)

WPBlkhd1

CONCRETE BULKHEAD AND MASONRY WALL STABILITY

The 4,000 psi concrete panel closure bulkheads must be capable of resisting the transient 480 psi design overpressure from a methane explosion within closed panels during the planned 35 year life of the facility. The panel closure bulkheads must also be capable of containing the continuous and rising air pressure resulting from the creep closure of the of the panel rooms for the planned 35 year life of the facility. Figure 7 indicates the air pressure inside a sealed panel could increase to approximately 100 psi over 35 years. The panel closure bulkhead designed for the 14-ft wide by 12-ft high Exhaust Drift (Figure 1) is 26-ft thick, 29-ft high and 33.5-ft wide. The panel closure bulkhead designed for the 20-ft wide by 13-ft high Intake Drift is 36-ft thick, 29-ft high and 35.5-ft wide.

In addition, it was postulated that "selection of a thick enough" optional explosion-isolation wall could isolate the main panel closure bulkheads from the design methane explosion pressure. A 12-ft thick, 3500 psi solid masonry concrete block wall mortared with 2500 psi mortar was selected for the explosion-isolation wall.

A 4-ft thick construction-isolation masonry wall is specified "to provide isolation during construction of the main concrete barrier." The panel closure bulkhead construction area will be isolated from the overpressure developed by a possible roof fall in the nearest waste filled room during the 6-month to one-year bulkhead construction period.

PANEL CLOSURE BULKHEADS

The purpose of the panel closure bulkheads, located in the Intake and Exhaust Drifts where indicated on Figure 9, is to seal the waste emplaced in the seven panel rooms from the remaining active, operational, part of the WIPP. Figure 11 shows a typical active panel with waste emplaced in two rooms and indicates the continuing ventilation of the waste filled rooms and panel access drifts. The tapered concrete bulkheads were also designed to block potential leakage paths along Clay G in the near roof and in the anhydrite Marker Bed 139 beneath the floor. Bed separation at Clay G and low angle shear fractures in the roof salt starting at the ribside and angling up to Clay G that preceded the two roof falls in the Site and Preliminary Design Validation (SPDV) area demonstrate the progressive damage in the immediate rock salt roof. Similarly, the fracturing and heave of room floors has been traced to upward buckling of the anhydrite Marker Bed 139. The need to remove the damaged rock zones (DRZ) and block the potential leakage paths in the roof and floor is the reason that the two-way tapered plain concrete bulkheads, shown on Figure 1, were designed.

The essentially rigid concrete panel closure bulkheads will draw load as the salt creeps toward the adjacent open drifts and rooms. The vertical and lateral horizontal stress acting on the roughly spherical panel closure bulkheads could eventually approach twice the overburden pressure, approximately 4,300 psi (Goodier, 1933; Edwards, 1955). The high stress concentration against the panel closure bulkheads will resist fracture propagation in the rock salt over, under and around the bulkheads, as indicated on Figure 12. The applied pressure would have to overcome (exceed) the rock salt/concrete contact pressure to propagate a fracture around the panel closure bulkheads.

The ground pressure applied to all sides of the panel closure bulkheads during the 17 years needed to reach an explosive 5% methane concentration (Figure 3) will grip the top, bottom and sides of the bulkheads. The force of this grip will resist flexure of the bulkhead concrete, in effect forming a fixed-end circular deep plate. The fixity of the panel bulkheads will reduce the bending moment developed when the bulkhead is loaded by the design explosion pressure applied from the waste emplacement side.

The ability of the planned plain concrete panel closure bulkheads was conservatively checked using the water impoundment bulkhead design method (Abel, 1998). The panel closure bulkheads are fully capable of resisting the 480 psi design methane explosion pressure. The 480 psi design methane explosion pressure is equal to the hydrostatic head of 1,108 feet of water. The panel closure bulkheads are effectively plain concrete because no tensile reinforcement is provided, or necessary, to resist the deep-beam bending stresses. The bulkhead lengths are sufficient to reduce the flexural bending stresses to less than the American Concrete Institute (ACI) allowable 206 psi tensile strength of 4,000 psi compressive strength concrete. Appendix A presents the calculations for the Intake Drift bulkhead and Appendix B for the Exhaust Drift bulkhead. Table 1 presents the various factors of safety for the panel closure bulkheads. The lowest factor of safety for the 36-ft thick Intake Drift bulkhead is 2.40 against both pressure gradient and concrete shear and for the 26-ft thick Exhaust Drift bulkhead is 1.54 against pressure gradient and 2.92 against concrete shear. The water impoundment bulkhead method only considers the grout pressure along the rock/concrete contact and does not provide any credit for the pressure from creep closure pressure of the rock salt.

The panel closure bulkhead design (Figure 1 and Figure 10) is not a monolith because it is planned to be built using four cells. The steel forms will restrain the concrete pumped into each cell until the initial set, which will take approximately 4 hours (Figure 13). Most water retaining bulkheads (Figure 4) are designed and constructed as monolithic, i.e. continuous, pours without cold joints or interior form walls. Figure 14 provides a longitudinal cross section of the reinforced concrete American Tunnel Bulkhead #1, designed to resist a 1550-ft head (670 psi) and supporting 1010-ft (438 psi). Note the waterstops on the bypass pipe and the grout holes drilled through the concrete to low-pressure grout the roof and rib contact between the 11,000 psi compressive strength latite porphyry and the 3,000 psi concrete.

Some multi-cell bulkheads have been constructed when construction problems or emergencies required. At the Summitville Mine a second 20-ft long cell was added when water loss through the 129 psi compressive strength altered latite porphyry and over the initial 6.5-ft long Chandler Adit bulkhead became excessive. At the West Driefontein Mine, in response to a 67,000 gpm water inrush, a three cell bulkhead was progressively constructed on the 12-Level, the initial "temporary" sand and cement bag diversion plug, followed by a 15-ft long thickening bulkhead against the "temporary" plug and the final 60-ft long sand-concrete extension bulkhead. At the Rocanville Mine, in response to a 6,250 gpm brine inrush into the potash mine, an 87-ft thick five cell bulkhead was constructed, an initial 8-ft thick bulkhead, a 16-ft thick second cell, a 25-ft thick third cell and a final 37-ft thick cell (Figure 15). In every case, the cell forms were externally supported and the internal bulkhead forms were stripped before constructing the subsequent cell. The planned four cell panel closure bulkhead construction would not provide a monolithic, i.e. uniform and continuous, bulkhead but could contain as many as three interior steel form walls supported during filling by the form spacers.

Penetrations through a water retaining bulkhead are normally minimized, whenever possible, because they represent potential leakage paths through bulkheads. Essential penetrations, such as bypass and sampling and pressure monitoring pipes, include waterstops to assure no leakage along the penetrations. The planned 4 cell panel closure bulkhead (Figure 1) includes the use of longitudinal 1-in diameter form spacers, which also support the facility side plate and angle form wall until the concrete sets. Figure 5 indicates 55 form spacer penetrations across Cell #2 and Cell #3. Figure 6 indicates 22 form spacer penetrations across Cell #1 and Cell #4. Multiple potential flow paths are apparent across the individual cells. If not removed after the cell is filled, the steel plate and angle forms provide multiple potential leakage paths between form spacers in adjacent cells. The bond strength between the steel plates and the concrete is necessarily low. Even if a way is found to remove the three interior steel form walls, after the concrete has set in each cell, a smooth surfaced cold joint will still be present between cells.

In order of declining potential effectiveness, the following panel closure bulkhead construction modifications should decrease the bulkhead leakage potential,

1) constructing truly monolithic single-cell panel closure bulkheads or
2) externally supporting the bulkhead cell forms, i.e. eliminating the form spacers, or
3) reducing the number of cells.

The panel closure bulkheads are tapered two-way pressure bulkheads, i.e. designed to resist equal pressure from either side. The panel closure bulkheads are apparently designed to be airtight for the 35-year life of the facility. Closure of the panel rooms and panel access drifts is predicted to result in 100 psi of effective pressure on the waste side of the bulkheads over a 35 years period after completion of the panel closure bulkheads (Figure 7). The two-way taper of the panel closure bulkheads was apparently designed to permit the safe excavation of the disturbed rock zones (DRZ) above and below the intake and exhaust drifts. The ample panel closure bulkhead factors of safety against the 480 psi design methane explosion pressure should be more than quadrupled for the closure pressure.

Tapered bulkhead water containment bulkheads are normally constructed when the rock shear strength is lower than the concrete design shear strength. Figure 4 shows a typical tapered water containment bulkhead, designed to resist hydrostatic pressure from one side. Successful tapered bulkheads have been constructed at the Summitville Mine, the Jackpot Mine declines and at IMC's K2 Mine. Tapering a bulkhead increases the length of the worst-case potential shear surface in the lower strength rock adjacent to the rock/concrete interface and tightens the concrete bulkhead against the rock when hydrostatic pressure is applied. In most water impoundment cases, when the rock strength exceeds the concrete strength, parallel plugs have proven to be effective. Loofbourow in the Society of Mining Engineers (SME) Mining Engineering Handbook (1973, Sec 26.7.4) states "no indication of structural failure resulting from thrust was noted" in the case of ten bulkheads subjected by hydraulic pressures in excess of 1000 psi and which relied solely on normal rock surface irregularities, referred to as a “parallel plug” on Figure 4. Garrett and Campbell-Pitt (1961) reported the successful results from 26 mine bulkheads, twelve with parallel plugs, that relied solely on the irregularity of the tunnel walls, and 14 with taper plugs.

Parallel panel closure bulkheads would probably be successful in resisting the potential applied pressures, Options A and B on Figure 10. However, the progressive deterioration of the adjacent rock salt and anhydrite and clay layer bed separations suggests that the two-way tapered bulkhead will assure the long term functioning of airtight panel closure bulkheads.

EXPLOSION-ISOLATION MASONRY WALLS

The 12-ft thick explosion-isolation masonry walls for the Intake Drift and the Exhaust Drift (Figure 2) are planned to be built with solid concrete blocks (3,500 psi) mortared with cement and hitched 6-in into the roof, ribs and floor. The explosion-isolation masonry wall is apparently designed to resist the 480 psi methane explosion pressure during the six months to one year of panel bulkhead construction.

The ability of the planned explosion-isolation masonry walls to resist the 480 psi methane explosion pressure was conservatively checked using the water impoundment bulkhead design method (Abel, 1998). Table 1 presents the results of this analysis. The calculations for the Intake Drift are presented in Appendix C and for the Exhaust Drift in Appendix D. The results of this analysis predicts that the planned 12-ft thick explosion-isolation masonry walls would not be capable of resisting the 480 psi design methane explosion pressure. The predicted failure of the explosion-isolation wall is indicated on Figure 12. In the Intake Drift, the thickness of an explosion-isolation masonry bulkhead would have to be approximately 20-ft to contain the 480 psi methane explosion pressure and in the Exhaust Drift approximately 15-ft.

Figure 3 presents the predicted 17+ year methane concentration time interval between cessation of panel ventilation and the methane concentration reaching the minimum 5% lower explosive limit. The predicted methane concentration should not exceed approximately 0.25% during a one-year panel closure bulkhead construction period. Therefore, a methane explosion should not be possible, and an explosion-isolation masonry wall not necessary.

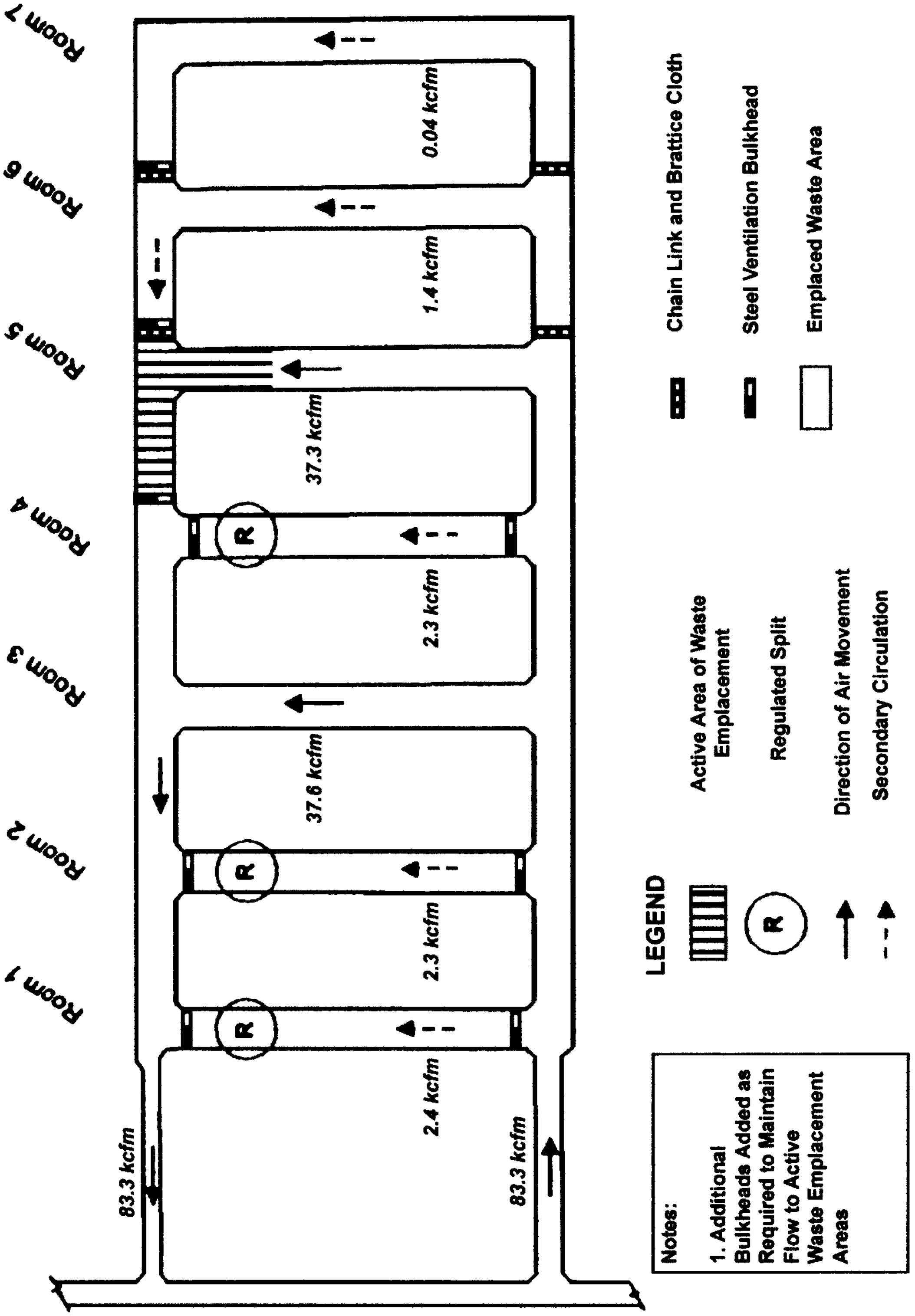
CONSTRUCTION-ISOLATION MASONRY WALLS

A 4-ft thick construction-isolation masonry wall has been designed to isolate the panel closure bulkhead construction from the emplaced waste in a completed panel and from the transient overpressure from a 15,000 ton roof fall in central 140-ft of Room 1 in the completed panel, closest to the Intake and Exhaust Drifts. The design roof fall is equal in weight and length to the roof fall in Site and Preliminary Design Validation Room 1 (SPDV1). The SPDV1 fall distance was the 13-ft room height, whereas the fall distance with emplaced waste drums is limited to 3.5-ft. Figure 16 presents the predicted 0.4 PSF (0.003 psi) maximum overpressure and the design 10.1 PSF (0.070 psi) air overpressure from the roof fall.

The ability of the planned construction-isolation masonry walls to resist the 0.070 psi design roof fall pressure was conservatively checked using the water impoundment bulkhead design method (Abel, 1998). Table 1 presents the results of this analysis. The calculations for the 4-ft thick Intake Drift construction-isolation masonry wall are presented in Appendix E.

The 4-ft thick construction-isolation masonry wall planned for the 20-ft wide by 13-ft high Intake Drift is fully capable of resisting the roof fall design overpressure. A similar 4-ft thick construction-isolation masonry wall planned for the 14-ft wide by 12-ft high Exhaust Drift will have even higher factors of safety against the roof fall design overpressure.

Figure 11.Typical active panel configuration with ventilation splits

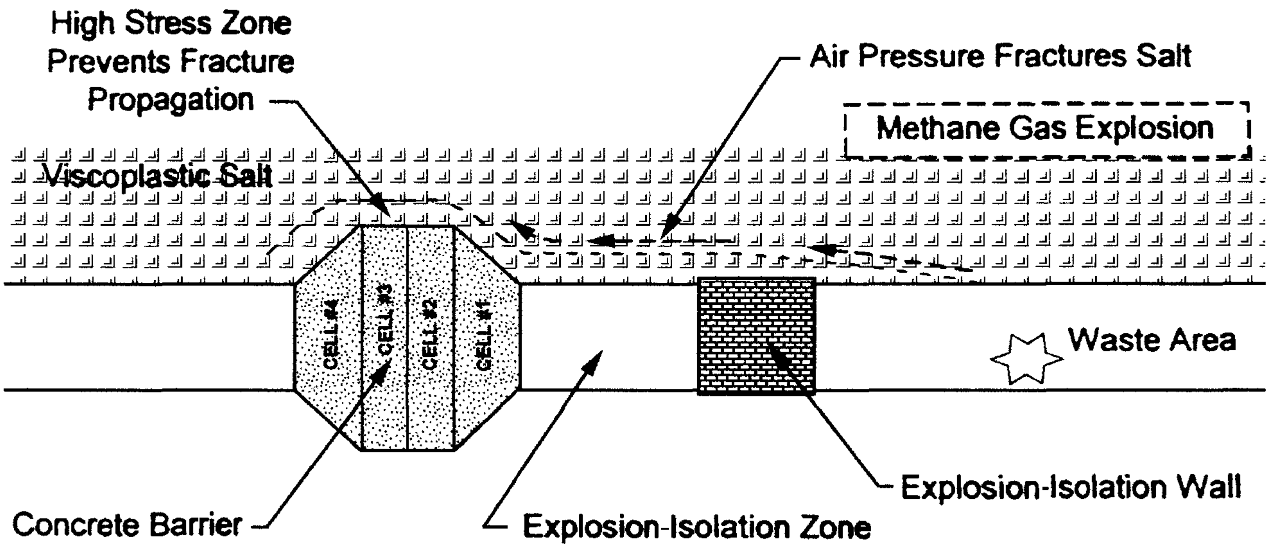


Notes:

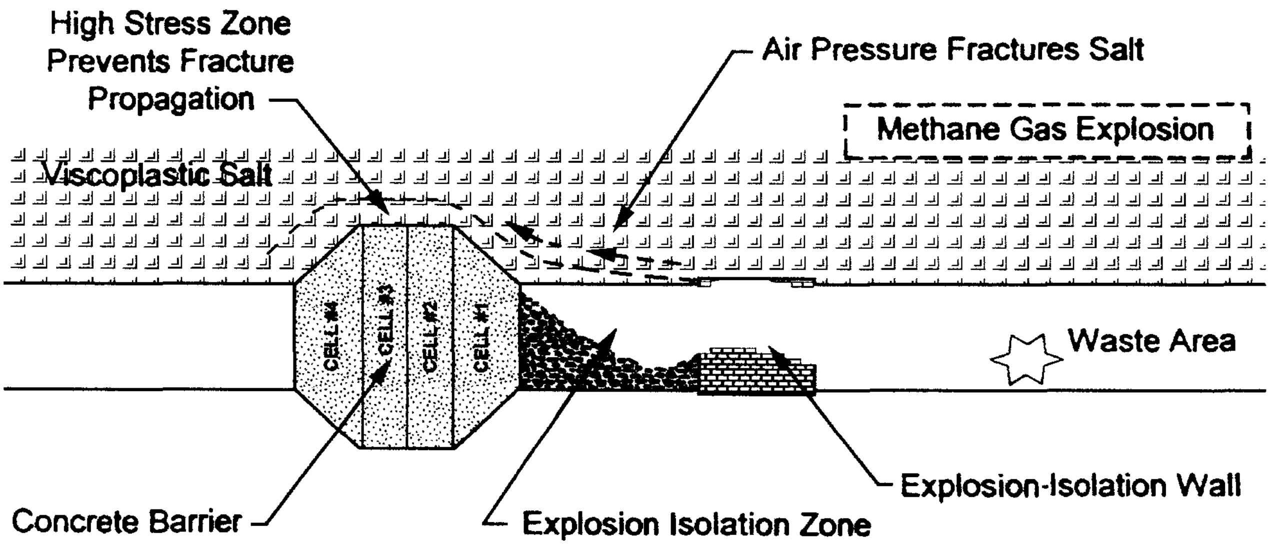
1. Additional Bulkheads Added as Required to Maintain Flow to Active Waste Emplacement Areas

Typical active panel configuration with ventilation splits (from Dykes, et. al., 1997)

Figure 12. Fracture propagation modes of bulkhead failure



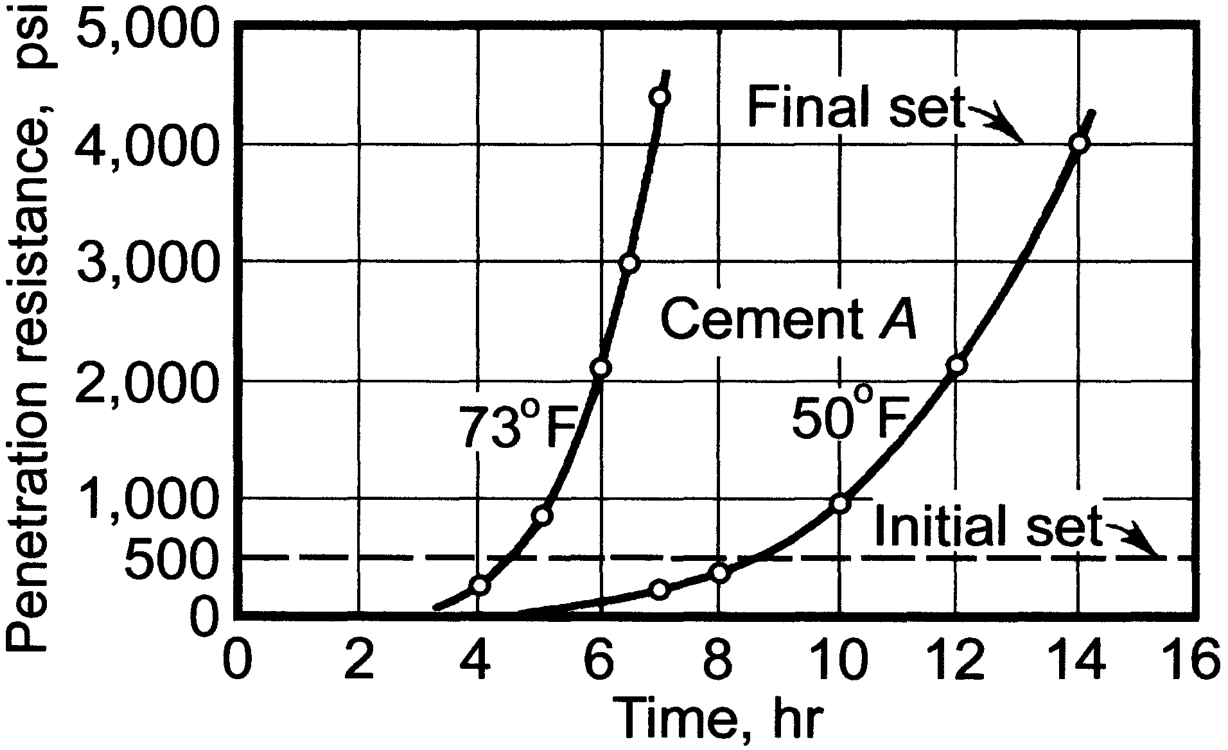
Fracture propagation mode of failure with stable explosion-isolation wall
(modified from Dykes, et. al., 1997)



Fracture propagation mode of failure for explosion-isolation wall failure
(modified from Dykes, et. al., 1997)

ExploBk1

Figure 13. Example of effect of temperature on setting time of concrete



Example of effect of temperature on setting time of concrete
(Troxell, et. al., 1968)

SetTime2

Figure 14. Cross section through monolithic bulkhead (Abel, 1998)

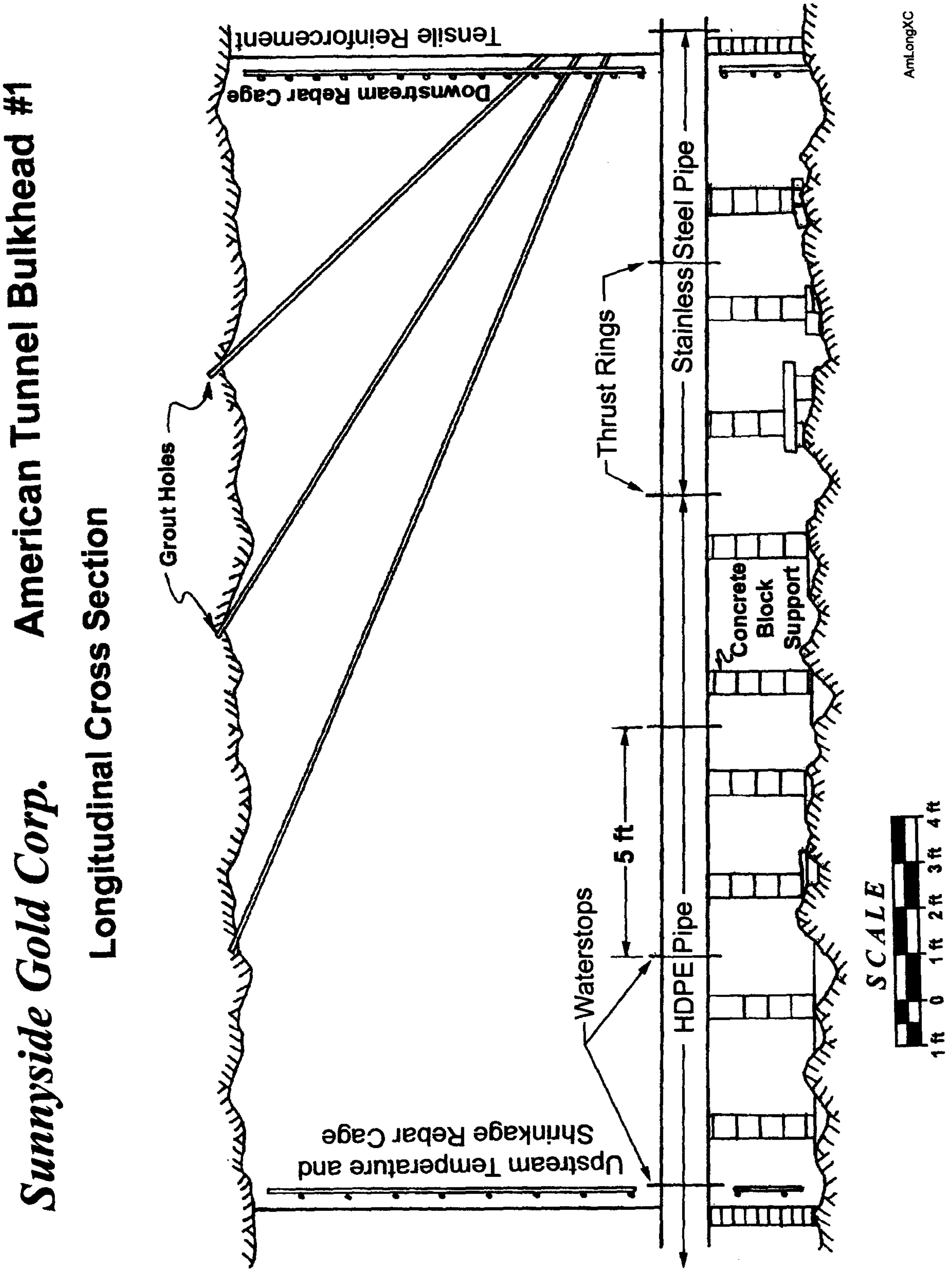
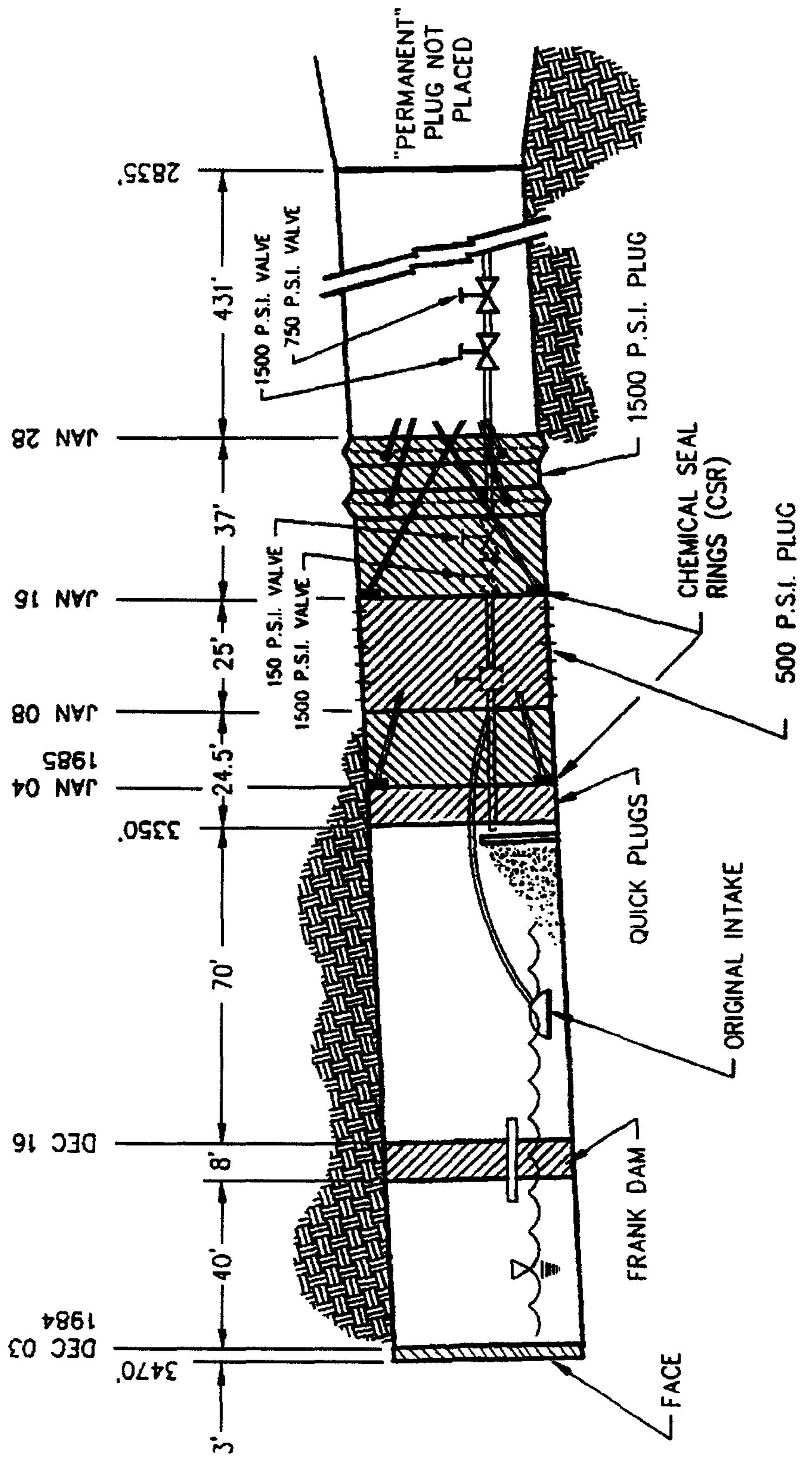
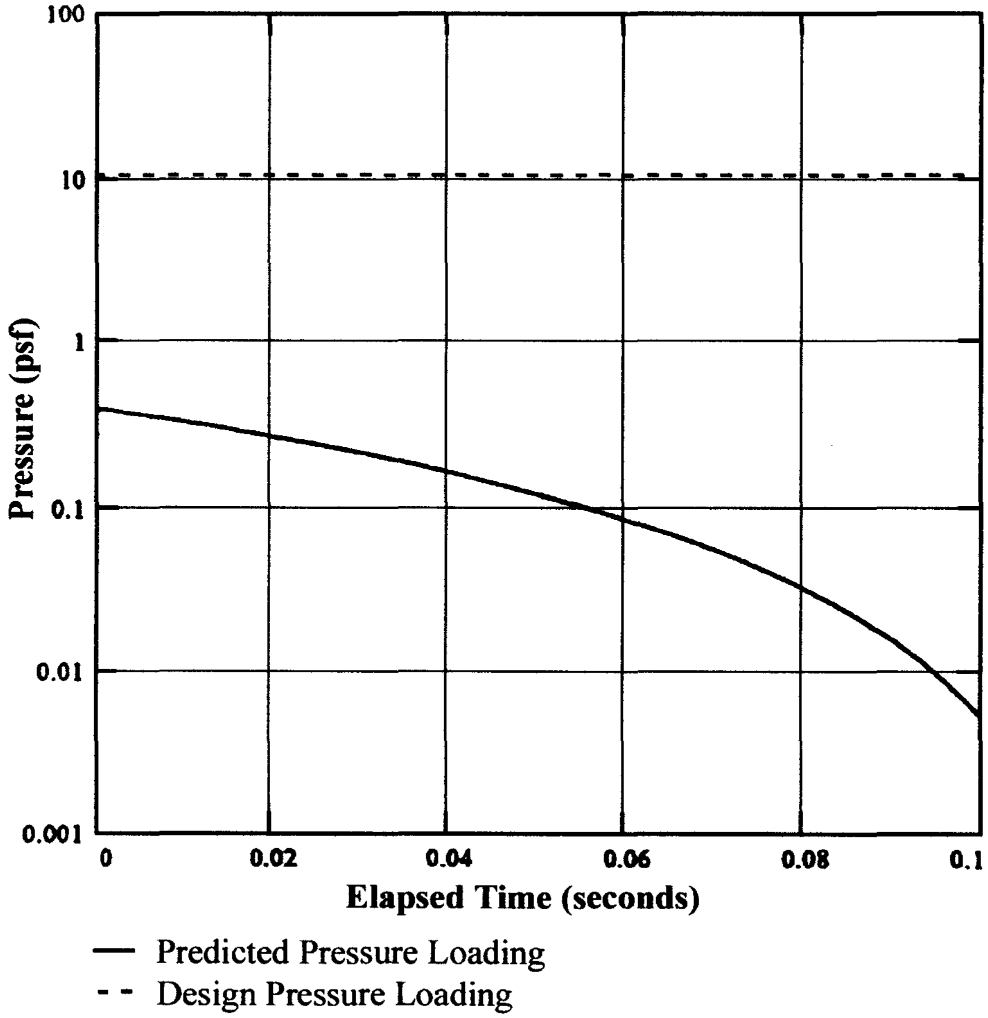


Figure 15. Rocanville inflow tunnel bulkheads and plugs



Rocanville inflow tunnel bulkheads and plugs (Eyermann, et. al., 1995)

Figure 16. Pressure transient from a roof fall



Pressure transient for a roof fall
(modified from Dykes, et. al., 1997)

RoofFall