C.2

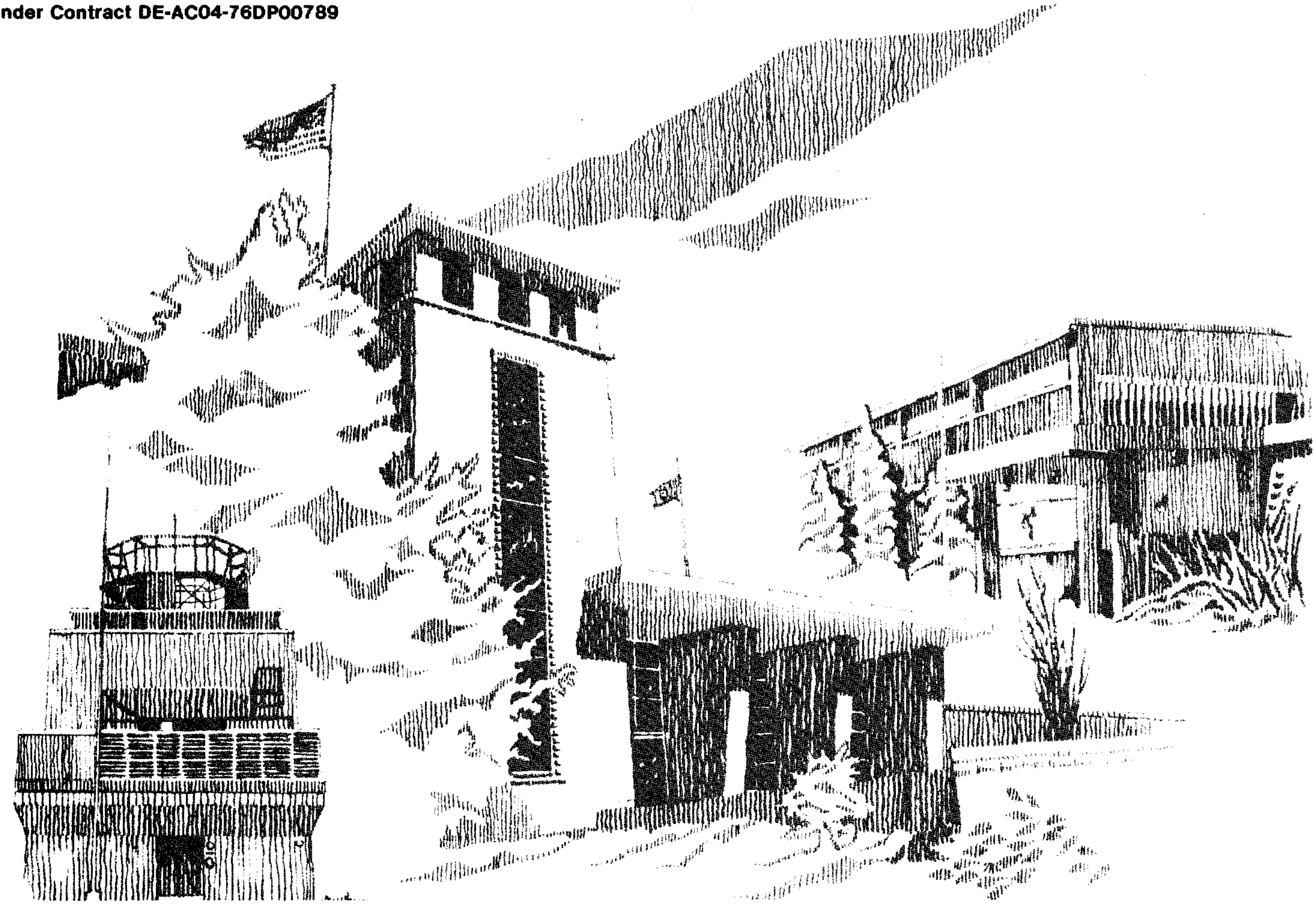
SANDIA REPORT

SAND90–0355 • UC–721
Unlimited Release
Printed May 1990

Initial Reference Seal System Design: Waste Isolation Pilot Plant

E. J. Nowak, J. R. Tillerson, T. M. Torres

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789



Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

SAND90-0355
Unlimited Release
Printed May 1990

Distribution
Category UC-721

INITIAL REFERENCE SEAL SYSTEM DESIGN: WASTE ISOLATION PILOT PLANT

E. J. Nowak, J. R. Tillerson, and T. M. Torres
Repository Isolation Systems Division
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

Waste Isolation Pilot Plant (WIPP) sealing program results are embodied in the initial seal system strategy and reference design. The design provides a common basis for calculations and analyses so that results can be compared directly. The sealing strategy combines both long- and short-term seal components. Crushed salt, consolidated by creep closure of the excavations, is the principal long-term barrier to fluid flow. Short-term seal components are used until creep consolidation is sufficient. Concretes developed specifically for WIPP seals and a swelling clay material that exhibits low permeability to WIPP groundwater and brine have been chosen for the short-term components. A body of evidence exists showing the stability of these materials for the length of time they are required to function. Reference designs are described and drawings are shown for each of the principal multi-component seals. Confidence in the sealing strategy and the reference designs resulted from a combination of laboratory tests, numerical modeling, and in situ demonstrations. The sealing strategy, materials, and designs for the WIPP repository are consistent with the concepts and designs proposed previously for other national and international waste management programs. Past accomplishments and planned activities in the sealing program will produce a detailed conceptual design for the seal system and a seal system performance model. Additional design, analysis, laboratory testing, and in situ testing are needed to assure the performance of the seal system.

CONTENTS

CONTENTS (CONTINUED)

TABLES

FIGURES

EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant sealing program has produced a sealing strategy that is embodied in this initial seal system reference design. The design provides a common basis for calculations and analyses so that results can be compared directly. The sealing strategy that combines short- and long-term seal components, and reconsolidated crushed salt as the principal long-term barrier to fluid flow. In the reference design, compacted crushed salt is emplaced at multiple locations within the shafts and various drifts; this salt then reconsolidates as a result of creep closure of the excavations. It is expected that, given sufficient time, the fluid conductivity within the seal will be reduced to nearly that of the host rock salt within the Salado Formation. Because there will be very little compositional difference between the reconsolidated WIPP crushed salt and the surrounding rock from which it was mined, the crushed salt is expected to be exceptionally stable, mechanically and chemically, in the seal environment. Short-term seal components, employing concretes developed specifically for WIPP seals and swelling clay material shown to be stable and to have low permeability to WIPP brines, provide the required sealing during creep consolidation of the crushed salt components. The disturbed rock zone (DRZ) that develops in the host rock salt at the excavated openings is expected to heal by creep closure. The DRZ of the shafts in the Rustler Formation and the interbeds in the Salado Formation are sealed by grouting techniques under development. The program has focused on developing and characterizing seal materials, evaluating the feasibility of the strategy, demonstrating the constructibility and performance of the seals, and obtaining the data necessary to support the design, construction, and performance analysis of the seals. A reference design was created to: provide a basis for sensitivity analyses, systems analyses and performance assessment; aid in the definition of sealing program activities; aid in the development of a detailed conceptual design; provide a common reference for interfaces with other WIPP programs.

In the reference design, multicomponent seals will be located in each of the four shafts, the entrances to the waste disposal panels, and selected access drifts. The designs for the seal components have progressed from schematic sketches for components used in the initial feasibility assessments to the set of reference drawings (Figures 2-11) provided in this report. The drawings include dimensions, planned locations, and preliminary materials specifications for all principal seal components of the reference design. The drawings also give alternate shapes being considered for concrete components.

Confidence in the sealing strategy and the reference design results from a combination of laboratory tests, numerical modeling, and in situ demonstrations. Laboratory testing demonstrated the relatively rapid consolidation of crushed salt under a wide range of pressures and provided data that were used to develop models for the calculation of

crushed salt reconsolidation in seals. Analyses of three coupled processes, namely, the expected creep behavior of the host rock salt, the expected reconsolidation behavior of preconsolidated crushed salt shaft seal components (emplaced at 80% of intact host rock salt density), and the expected brine inflow rate, indicate that crushed salt components will reconsolidate sufficiently within 100 years after emplacement to restore the fluid conductivity of the seal to near that of the original formation. Confidence has also been provided by the successful development of site-specific concretes and grouts compatible with host rock in the WIPP, and by the successful in situ emplacement of crushed salt and bentonite blocks in small-scale horizontal and vertical seal environments. Additional confidence in the seal system design and information for its further development will be derived from current and future activities in the Seal System Development Program.

The sealing strategy, materials, and reference design for the WIPP respository are also consistent with the concepts and designs proposed in other national and international programs. Creep closure of a lengthy column of crushed salt is the same strategy employed in the research program in the Federal Republic of Germany and in the seals proposed for the salt formations evaluated in the U.S. high-level nuclear waste repository program. In addition, the short-term seal components are similar to many of those under consideration in the German and Swedish programs; indeed, much of the demonstration of the capabilities of swelling clay (bentonite) components has been provided by the Swedish testing program.

Substantial additional research, development, and design must be completed to assure the performance of the seals. The principal activities include additional laboratory tests to provide a data base sufficient for performance assessments of crushed salt reconsolidation and seal material compatibility with the host rock and waste, as well as developing specifications to define the allowable variability in the emplaced materials. Also, additional design work is planned to provide details of the design criteria, components, excavation techniques, surface preparation and tolerances, emplacement methods, grouting techniques, materials specifications, and principal quality assurance/quality control requirements. Additional analyses will include shape studies for the concrete components and structural and hydrologic performance calculations. Models of the seal system behavior, consistent with the seal designs and the data that characterize the host rock, are also being developed for use in seal system sensitivity studies and in overall performance assessments. Finally, additional data are needed from field tests of seals and, particularly, in situ measurements of the extent and properties of the DRZ that develops in the host rock at the excavated openings. Large-scale in situ tests of seals are planned as part of the progression of testing that supports the seal evaluations. These tests are expected to demonstrate the construction feasibility of the components and to provide data on their initial post-emplacement performance. Major products of the planned program and other program elements are described in Section 7 and depicted with interrelationships in Figure 1.

1. INTRODUCTION

Presented in this report are: (1) the general WIPP sealing strategy that guided development of the reference design; (2) a reference seal system design to carry out the sealing strategy; (3) information that provides confidence in the strategy and design; (4) alternative seal system concepts and designs; (5) seal system decisions that have yet to be made; and (6) new information required to make the decisions, along with an R&D program and timetables. The sources of redundancy in the systems are also highlighted, and the required temporal performance for seal components is given.

The body of this report describes the WIPP reference seal system, including the general sealing strategy, the reference seal system drawings, the temporal sequence of seal system functions, multiple functions and redundancy in the seal system, and materials selection and compatibility. Then, designs for the lower shaft seal system, the upper shaft seal system, the drift and panel seal system, and the sealing of the disturbed rock zone (DRZ) are described. The repetition of information in each section dealing with a major seal system is intentional. Thus, for example, the reader is not required to identify and extract from a section that covers all seal systems the specific information about concrete for the lower shaft seal system. Next, applicable information from other waste management programs is presented to show the support that they afford for the WIPP designs. Finally, the principal activities for future seal system development, conceptual design, and validation are given. A glossary of the seal-specific terms, some of them appearing in the text and drawings, is given in Appendix A.

1.1 Overall Performance Objectives for WIPP Seals

The overall seal system limits release of radionuclides and other hazardous waste species through each man-made penetration and the DRZ that surrounds it (Stormont, 1984; Stormont, 1988). The seal system also limits the inflow of groundwater from overlying water-bearing zones to the Salado Formation for two reasons: to prevent interstitial brine from inhibiting the rapid reconsolidation of crushed salt seal system components (although preliminary laboratory test results do not indicate an inhibiting effect of initial brine-saturation on the reconsolidation rate); and to limit the water content of waste disposal areas in the WIPP. Seals will also be designed to attenuate the flow rates of gas that may be generated by corrosion and microbiological processes in the waste disposal area. Seals will be designed to withstand the pressures applied by flowing gases.

1.2 Purposes of the Reference Design

The reference design provides a common basis for calculations and analyses so that results can be compared directly. Examples are ongoing systems analyses of WIPP seals and the WIPP repository, sensitivity analyses that relate performance to changes in components and parameter values, and performance assessment calculations. The reference design will also be a tool to define ongoing and future sealing program testing, component analysis, and design activities. It contains initial design details that are a starting point for the development of a detailed conceptual design. Finally, it provides a common reference for information exchange with other WIPP programs.

1.3 Technical Background and Program

A large body of technical background information was generated and used in the development of this design. Most of that information resulted from the WIPP sealing program; some of the material came from other waste management programs and is given in Section 6.

The WIPP sealing program has four areas of activitiy: design, analysis (including model development and calculations), laboratory testing, and in situ testing (including DRZ characterization). Past, ongoing, and planned activities in the sealing program are focused on producing a detailed conceptual design for the seal system and a seal system performance model. These major products of the program, program elements such as supporting reports, analyses, designs, and test implementation, and related activities are described in Section 7.

Activities in all four areas contributed to the current reference design. Sealing objectives, concepts, and schematic designs were formulated early in the WIPP sealing program (Stormont, 1984). Candidate material types and formulations were chosen to meet these initial objectives. Materials development, laboratory testing, and evaluation (Krumhansl, 1984; Gulick and Wakeley, 1989; Holcomb and Shields, 1987) led to the selection of materials for this reference design. Small-scale in situ tests established the feasibility of manufacturing and emplacing these materials (Stormont, 1986; Stormont and Howard, 1986; Stormont and Howard, 1987). Information on brine inflow from the Salado Formation, and on creep closure of excavations were obtained from other WIPP programs. Models of brine inflow and creep closure were coupled with models of seal materials behavior to calculate candidate seal component performance and to establish the viability of the initial schematic seal component and system design (Sjaardema and Krieg, 1987; Nowak and Stormont, 1987; Arguello and Torres, 1987; Stormont and Arguello, 1988). DRZ characterization by in situ fluid flow testing was begun early in this program in parallel with the above activities. Interim results from DRZ studies (Borns and Stormont, 1988) were used to formulate sealing requirements for the DRZ. Some of these results were summarized in a report (Tyler et al., 1988). These results were assessed in a preliminary seal design evaluation

(Stormont, 1988) and were used in a WIPP systems analysis (Lappin et al., 1989)

The six principal WIPP sealing system references are Borns and Stormont (1988), Lappin et al. (1989), Nowak and Stormont (1987), Stormont (1984), Stormont (1988), and Stormont and Arguello (1988).

2. WIPP SEAL SYSTEM

This section presents the general sealing strategy, characteristics of the disturbed rock zone (DRZ), reference seal system drawings, the temporal sequence of seal system functions, the multiple functions and redundancy in the seal system, and materials selection and compatibility issues.

2.1 General Sealing Strategy

Sealing functions for waste isolation are carried out by a combination of short-term and long-term seals. Short-term seals provide the initial sealing functions necessary until the long-term crushed salt seal components become adequately consolidated by creep closure of the host rock salt. Crushed salt components are expected to become fully functional for sealing within 100 years after emplacement (Nowak and Stormont, 1987; Arguello, 1988). Then, the long-term seals take over all sealing functions. The DRZ at all seals in Salado Formation host rock salt, excluding interbeds, is expected to offer significant flow resistance initially and to be sealed by self-healing during creep closure. Sealing the DRZ in interbeds and in the Rustler Formation is treated in the next section.

The short-term seals consist of swelling clay and concrete components in shafts, drifts, and panel entries. The swelling clay components limit water inflow from above to protect the crushed salt from saturation with brine. The concrete components provide flow resistance to control the effects of possible gas generation in the waste disposal area; they also provide physical containment for the swelling clay and consolidating crushed salt materials. Tight concrete bonding to rock is not required for these functions, and high expansion concrete is desirable but not essential. The short-term seals may continue to function effectively for much longer than 100 years, providing sealing redundancy.

The long-term seals consist of consolidated WIPP crushed salt in the shafts, drifts and panel entries. Within 100 years of emplacement, these seals are fully consolidated by creep closure of the host rock salt to a state of low permeability, approximately 10^{-20} m^2 (Nowak and Stormont, 1987; Arguello, 1988; Lappin et al., 1989). That is in the expected permeability range for the host rock salt (10^{-21} to 10^{-20} m^2) (Nowak, McTigue, and Beraun, 1988; Lappin et al., 1989). There is very little compositional difference between the reconsolidated WIPP crushed salt seal material and the surrounding host rock salt from which it was mined; the crushed salt seals are therefore expected to be mechanically and chemically stable in the WIPP environment for the required lifetime of the seal system.

Design criteria for seismic activity and geologic faulting are not considerations in the reference design. There is no evidence for local tectonic deformation in the Delaware Basin since Permian time. No tectonic faults have been discovered in the WIPP area, and no earthquake epicenter has been found within about 25 miles of the WIPP site (R. L. Hunter, 1989). Because of the physical unreasonableness and low probability of faulting, it was screened from the WIPP performance assessment (Hunter, 1989). Although no significant seismic hazard is apparent now, the need for seismic-related design criteria will be evaluated further.

2.2 Disturbed Rock Zone

The DRZ may impact the performance of a drift, panel, and shaft seals. Sealing and flow in the DRZ of the salt and the interbeds in the Salado Formation are presented first. Then, sealing the DRZ of the upper shafts in the Rustler Formation is discussed.

2.2.1 Shaft, Drift, and Panel Entry Walls Near Seals in the Salado Formation, Excluding Interbeds

With the exception of nearby interbeds such as Marker Bed 139 (an anhydrite-containing layer), the DRZ near all seal emplacements in the Salado Formation is expected to exhibit some resistance to fluid flow initially and to present a very high resistance to fluid flow as it "heals" by creep closure of the host rock. This expectation is based on laboratory observations that WIPP core samples, under pressure, "self-heal" by creep-resealing of fractures (Borns and Stormont, 1988; Lappin et al., 1989). The information available at this time indicates that the DRZ in the Salado Formation near the shaft seals may be be the least conductive to fluids. Sealing is not expected to be needed in the DRZ outside of the interbeds. The reference design does include grouting and other sealing techniques for the interbeds.

An ongoing program is characterizing the temporal and rehealing behaviors of the DRZ at WIPP excavations in the Salado Formation. Information from this program will be used to choose seal locations and to predict the overall hydraulic conductivity as a function of time.

2.2.2 Interbeds Near WIPP Excavations

Fractures have been observed in interbeds near WIPP excavations (Borns and Stormont, 1988). Fractures in materials such as Marker Bed 139 anhydrite are likely to heal incompletely or at least more slowly than those in relatively pure halite and retain significant fluid transmissivity (Borns and Stormont, 1988; Lappin et al., 1989). Therefore, at critical drift seal locations, fractures in Marker Bed 139 and in other beds that may be identified, are filled with anhydrite-compatible, deformable seal materials such as grout, crushed salt, swelling clay, or bitumen.

The seal material in interbeds is expected to be compatible with WIPP rock types over very long times, as evidenced by long-term, geologic stability of the material (e.g., crushed-salt-based grout or bitumen). This seal material is expected to have an effective permeability as low as or lower than the measured values from WIPP small-scale seal in situ tests (Lappin et al., 1989). An average effective permeability of 4 x 10^{-19} m^2 has been calculated for emplaced cementitious material using data from WIPP Small-Scale Seal Performance Test Series A and B (Peterson et al., 1987; Lappin et al., 1989).

An ongoing program characterizing interbeds (e.g., Marker Bed 139) and developing grouts and grouting techniques includes compatibility studies that consider host rock materials, nearby seal materials, and waste disposal room contents as interacting elements. Crushed-salt-based grouts, bitumen-based grouts, and grouts based on cementitious materials are among those being considered.

2.2.3 Shaft Walls in the Rustler Formation

There is also an ongoing hydrologic testing program in the Air Intake Shaft to predict properties of the DRZ in the host rocks of the WIPP shafts in the Rustler Formation. Grout formulations and grouting techniques are to be developed for Rustler Formation rocks, particularly anhydrite. Grouting is specified for the upper shaft seal locations in the reference seal design.

2.3 Reference Seal System Drawings

Drawings TRI-46-1 through TRI-46-5 (shown in Figures 2-11) depict the current reference seal system design that embodies the short-term/long-term sealing strategy. The general WIPP facility seal arrangement is given in Figure 2. The drawings evolved from design concepts, sketches, and schematics that have been published (Stormont, 1988; Lappin et al., 1989). These drawings are marked "information only," because they are not for the purpose of construction.

E. J. Nowak assumed primary technical responsibility for preparing, reviewing, and approving the drawings. For Quality Assurance purposes, the drawings were reviewed and approved by J. A. Fernandez (SNL, Division 6314) , T. E. Hinkebein (SNL, Division 6314), and T. M. Torres (SNL Division 6346). Fernandez and Hinkebein are qualified by their experience in seal design for the Yucca Mountain Project. Torres has performed technical analyses of seal components for the WIPP.

The term "reference" describes a design, a material composition, a set of material properties, or a set of shapes or dimensions chosen to promote consistency and comparability among the results of tests, analyses, and evaluations. In general, the reference materials and designs are realistic, feasible, and appropriate for WIPP seal systems and their further development.

2.4 Temporal Sequence of Seal System Functions

Concrete seal components and associated grout in the interbeds will be the first to become fully functional in the seal system. Initial curing for each concrete seal component will be completed approximately 28 days after emplacement. At that time, the initial material specifications given in Figure 11 will be met. The initial curing period for grouts in interbeds, if any, will also be 28 days or less. The DRZ in the salt around drift and panel seals is also expected to offer significant resistance to gas flow initially and may offer increasing resistance as fractures in the DRZ heal by creep closure (Lappin et al., 1989). Available information indicates that the DRZ near the shafts in the Salado Formation may have lower hydraulic conductivity than near the drifts and rooms at the repository horizon.

The initial functioning of concrete components will follow the sequence of seal component emplacement: panel seals, drift seals, then shaft seals. A reference sequence of emplacement for panel and drift seals is given in more detail in Figure 8. Shaft seals, shown in Figure 3, will be emplaced starting at the bottom of the shaft and proceeding upward to the top. Groundwater or brine emanating from water-bearing zones in the Rustler Formation will be collected and removed until underlying seal materials have been emplaced and concrete components have cured. After it is emplaced, the upper seal system will limit the flow of water from the Rustler Formation into the Salado Formation to allow complete consolidation of the crushed salt shaft seal components in the Salado.

The functional lifetime of the concrete seal components will be at least 100 years and probably longer. They will meet the material specifications given in Figure 11. Laboratory data and chemical understanding of the concrete/groundwater system confirm the longevity of the concrete. Concrete components are not required to function beyond 100 years, because consolidated crushed salt components will provide the controlling hydraulic resistance in the seal system within the 100-year period.

The clay components will be functional immediately after they are emplaced and contained by the concrete components, but they must absorb some water or brine before they swell and have the required low permeability. Although absorbed rapidly, water is bound by the clay and does not pass through it. After the clay is saturated and swells, it exhibits a very low conductivity for water flow. The clay components in the upper seal system are expected to be the first to swell and control water flow from the Rustler Formation. This flow control function is required for the first 100 years after emplacement. Eventually, all of the clay components are likely to absorb groundwater or brine from the surrounding host rock, swell, and reach a state of low permeability.

The clay may remain functional longer than the required 100 years, thereby providing sealing redundancy.

The crushed salt components will be the last to become fully functional. Within 100 years, the crushed salt will be consolidated to nearly the same permeability that is exhibited by the host rock salt. At that time, consolidated crushed salt will provide the controlling hydraulic resistance, which is expected to last for at least 10,000 years. Additional data and numerical analyses are required for detailed temporal predictions of the hydraulic conductivity for the crushed salt seal components. The first crushed salt components expected to be fully reconsolidated are those in panels and drifts, in the order of emplacement (described in Figure 8). Preliminary estimates of reconsolidation times are given by Arguello (1988) for drift and panel crushed salt seal components and by Nowak and Stormont (1987) for crushed salt seal components in shafts.

2.5 Multiple Functions and Redundancy in the Seal System

The system includes multiple sealing components for redundancy and to carry out multiple functions. These components are located in the four shafts, the four access drifts, and the entrances to the waste disposal panels, as shown in Figure 2.

Multiple seals are located in the upper shaft for redundancy. Because saturation by brine may inhibit the consolidation of crushed salt, control of brine inflow from the Rustler Formation is the principal determinant of performance requirements for the upper shaft seal system. The upper shaft seals are designed to limit groundwater flow into the lower shafts from water-bearing zones in the Rustler Formation until reconsolidation of crushed salt in the lower shaft is sufficient for sealing effectiveness.

Short-term seals in the lower shaft provide short-term waste isolation, gas flow control, and redundant water inflow control for approximately 100 years after emplacement. The column of crushed salt in the lower shaft seal system is the primary long-term barrier to the escape of hazardous waste components from the repository horizon.

Drift and panel seals provide additional resistance to the escape of hazardous waste materials and help mitigate the potential effects on the shaft seal system of gas generation in the waste disposal area. They also attenuate gas flow from the waste disposal area.

2.6 Materials Selection and Compatibility

Crushed salt mined from the WIPP has been chosen as the sole long-term seal material. There is very little compositional difference between the crushed salt and the rock salt from which it was mined. Laboratory studies and numerical analyses have shown that crushed salt emplaced in WIPP excavations will be consolidated by creep closure to a hydraulic conductivity approaching that of the host rock salt itself (Holcomb and Shields, 1987). No other materials have been found to be as stable and to have such a low hydraulic conductivity. Therefore, the crushed salt seals are expected to remain mechanically and chemically compatible with the WIPP environment for the required lifetime.

This reference design incorporates short-term sealing materials that have been tested in the WIPP program and in other waste management programs. The chosen materials work well in the current seal system. For example, swelling clay material is in the current reference design, because the swelling pressure can be tailored by controlling its emplaced density, and the geochemical stability of bentonite swelling clay in WIPP brines has been tested (Krumhansl, 1984). Other seal materials, such as bitumen, will be retained as options until the final seal designs are chosen.

The potential for degradation of short-term seals by interactions between transuranic waste and the reference seal materials is being evaluated. Interactions identified for evaluation are mechanical and chemical. Pressure may be applied to seal components by gases generated in the waste disposal area by microbiological activity and corrosion. Chemical reactions may occur among reactants from the waste and the seals.

Mechanical degradation of seals by gas pressure is very unlikely, because gas escape from the waste disposal area is expected to be gradual, and the source pressure is not expected to exceed lithostatic by more than the crack clamping stress. Pressures due to this gas flow are expected to be attenuated to values lower than lithostatic in steps by the hydraulic resistances of each of the intervening concrete and grout drift seal components and associated DRZs between the waste area and seals in the shaft. Each concrete seal component will be designed to withstand a pressure difference that equals or exceeds the local lithostatic confining pressure. Therefore, design pressures cannot be exceeded. The forces due to consolidating crushed salt will be included in the design process. More detailed analyses of the mechanical stability of seal components in the presence of flowing gas are planned.

Slow reactant transport rates are expected to limit chemical interactions of seals with the waste. Gas-phase convection and diffusion are the only available transport mechanisms for chemical reactants from the waste during the first 100 years after the operational period, because the repository is anticipated to remain unsaturated during the period. The consolidation of crushed salt seal materials will take place during the 100-year period. After consolidation, the long-term crushed salt seals will have very low hydraulic conductivities comparable to those of the Salado Formation; therefore, over the long term, chemical interactions with waste materials should become increasingly unlikely. The likelihood that any significant deterioration of seal materials could result from such interactions is being evaluated.

Also being evaluated are potential chemical interactions among seal components. Currently identified for study is the effect of locally increased pH due to concrete/water reactions on swelling clay at the concrete/clay interface.

3. LOWER SHAFT SEAL SYSTEM

The functional requirements, seal system reference concept, and individual seal components for the lower shaft seal system are described in this section. The lower shaft seal components include swelling clay, concrete, and crushed salt (see Figures 6-7).

3.1 Lower Shaft Seal System Functional Requirements

The long-term functional requirement for the lower shaft seal system is to return the lower portion of each shaft to a permeability to fluids comparable to intact rock salt within 100 years (Nowak and Stormont, 1987). Thus, within 100 years, the lower shaft becomes a flow barrier equivalent to the host rock salt. The short-term components of the lower shaft seal system function as redundant barriers to the intrusion of water from the upper water-bearing zones in the Rustler Formation and as resistances to the flow of gases. This short-term seal function continues to be necessary until the long-term functional state of the seal system has been reached by the reconsolidation of emplaced crushed salt due to creep closure of the shaft walls.

3.2 Lower Shaft Seal System Reference Concept

The crushed WIPP salt primary seals in the lower shaft are confined by concrete bulkheads and the surrounding rock until sufficient consolidation has been achieved. The concrete components also resist the flow of gases. The limited information available indicates that the DRZ in the Salado Formation near the shaft seals may have low hydraulic conductivity. Therefore, the short-term concrete seal components in the shafts are expected to a become effective resistances to the flow of liquids and gases very soon after the 28-day curing period. Swelling clay (e.g., bentonite) components provide redundant protection from infiltration by water from upper shaft water-bearing zones or other potential sources above or below the Salado Formation.

3.3 Lower Shaft Seal Concrete Components

Concrete components will be located in the shafts within the Salado Formation. Their locations within the entire shaft seal system are shown in Figure 3. They are described in more detail in Figure 6. Concrete components will be emplaced as end-members of composite seals containing preconsolidated crushed salt and swelling clay material.

Containment of preconsolidated crushed salt and swelling clay components, and resistance to fluid flow are the major roles of the concrete components. Equivalent permeabilities on the order of 10^{-19} m^2

to 10^{-20} m^2 have been measured after one year for concrete emplacements in the Salado host rock (Peterson et al., 1987).

Reference physical dimensions (Stormont, 1988) have been derived from concrete seal length criteria (Garrett and Pitt, 1958; and 1961) and numerical analyses (Van Sambeek, 1987). The reference length is 10 m, and keyways are envisioned to support axial loads from the mass of the concrete, clay swelling pressures, consolidating crushed salt, and potential gas generation in the waste disposal area. Possible concrete shapes have been presented (Stormont, 1988), and alternative reference shapes are shown in Figure 10. Reference designs for all shafts, including dimensions, are given in Figure 6. The definitions of shapes (e.g., keyways, tapers, curves) continue to be refined using numerical models and other analyses.

The reference concrete formulation for lower shaft seals in the Salado Formation halite (Gulick and Wakeley, 1989) is given in Table 1.

Table 1. Reference Concrete Formulation for Lower Shaft Seals.

Material	Proportion (wt%)
Fine local (Carslbad, NM) aggregate	~35
Coarse local (Carlsbad, NM) aggregate	~35
BCT-1F grout	~30

The reference BCT-1F salt-saturated grout, developed specifically for WIPP applications in the Salado Formation, has been extensively characterized (Gulick and Wakeley, 1989). The grout exhibits low heat evolution, durability, high density, low permeability, and desirable but not essential high expansion. It is prepared with the formulation given in Table 2.

Table 2. Reference BCT-1F Salt-Saturated Grout

Material	Proportion (wt%)
Class H Cement	48.3
Class C Fly Ash	16.2
Cal Seal (Plaster)	5.7
Sodium Chloride (NaCl)	7.9
Dispersant	0.78
Defoamer	0.02
Water	21.1

Concrete formulation is continuing. The mechanical stability of concrete components also continues to be addressed via calculations. Curing and stress analyses are planned.

Initial results from tests and literature reviews (Stormont, 1986; Stormont and Howard, 1986; Wakeley, 1989;) support the expectation that grouts and concretes will be stable in halite and in brines that have a high sodium chloride content. The chemical stability of concrete and concrete compatibility with WIPP brines, WIPP salt, swelling clay, and the contents of waste disposal rooms continue to be assessed.

The feasibility of emplacing concrete components in vertical WIPP excavations has been demonstrated by emplacements of several small-scale (1 m diameter, 1 m long) concrete bulkheads in vertical boreholes underground (Stormont, 1986). A local concrete supplier and typical industrial concrete-handling equipment were employed. The performance of these emplacements was verified, because equivalent permeabilities on the order of 10^{-19} to 10^{-20} m^2 (Peterson et al., 1987) were measured within 1 year after emplacement. Large-scale in situ tests applicable to shaft seals are being planned.

3.4 Lower Shaft Seal Swelling Clay Components

Swelling clay (e.g., bentonite) components will be located in the shafts within the Salado Formation. Their locations within the entire shaft seal system are shown in Figure 3. They are described in more detail in Figure 6.

The swelling clay components provide redundant protection of consolidating crushed salt from infiltration by water from strata outside the Salado Formation. Low permeability and swelling upon uptake of water are well-known properties of swelling clay materials such as bentonite. These properties have been studied extensively for application to the isolation of radioactive waste (Coons et al., 1987). Calculations show that a single bentonite seal of 4 m length can sufficiently reduce water flow from overlying strata to protect underlying crushed salt from saturation (Stormont and Arguello, 1988).

The reference length of 4 m for the swelling clay components was derived from empirical length requirements for clay seals (Stormont, 1988; National Coal Board, 1982). The reference shape is cylindrical. Reference designs for all shafts, including dimensions, are given in Figure 6.

The swelling clay is expected to remain stable and effective for much longer than 100 years (Stormont, 1988). Clays exist naturally in geologic formations, including bedded salt. Evidence for the effectiveness of clay as a sealant for more than 2,000 years has been reported (Lee, 1985). The transformation of bentonite to nonswelling minerals, although possible, is expected to be very slow at WIPP ambient temperatures (Meyer and Howard, 1983). Experiments in WIPP-specific brines (Krumhansl, 1984) showed that bentonite should remain effective in the WIPP for longer than 100 years. The initial density of swelling clay components will be tailored to swelling pressure requirements and the limits imposed by local lithostatic pressure and load-bearing capacities of concrete retaining structures. The compatibility of swelling clay materials such as bentonite with reference concrete and, if necessary, waste disposal room contents will be evaluated.

3.5 Lower Shaft Seal Crushed Salt Components

The reference configuration includes preconsolidated (tamped) crushed WIPP salt in two types of emplacements: as the primary long-term shaft seal, two emplacements between composite seals located near the bottom of the shaft, at an intermediate position in the shaft just below the Vaca Triste Marker Bed, and near the top of the Salado Formation; for redundancy, an emplacement at the center of each of the composite seals. The locations of tamped crushed salt components within the entire shaft seal system are shown in Figure 3. They are described in more detail in Figure 6.

The emplaced WIPP crushed salt is intended to have a reference initial density equal to 80% of the density of intact WIPP host rock salt (80% relative density). That initial density will be achieved by pouring and tamping crushed salt or by laying preconsolidated salt blocks. The feasibility of manufacturing crushed WIPP salt blocks with 80% relative density has been shown (Stormont and Howard, 1987). Creep closure of the lower part of the shaft will continue to consolidate this crushed salt.

An analysis of crushed salt consolidation in a WIPP shaft showed that 95% of intact salt density will be reached in the lower shaft within approximately 100 years. The permeability of the consolidated salt at that density is expected to be 1×10^{-20} m^2, with an expected range of 3×10^{-21} to 3×10^{-20} m^2 (Nowak and Stormont, 1987; Lappin et al., 1989). The expected height of the final column of consolidated salt having 1×10^{-20} m^2 permeability is 200 m in each shaft, according to an analysis that used the best current representation of expected reconsolidation (Nowak and Stormont, 1987; Lappin et al., 1989). The expected range is 100 to 200 m (Nowak and Stormont, 1987; Lappin et al., 1989). The expected height may be conservatively small, because the analysis assumed that brine-saturation of the reconsolidating salt inhibits further consolidation. Preliminary results from recent laboratory studies indicate that brine-saturation may not inhibit reconsolidation.

Ongoing laboratory studies of WIPP crushed salt consolidation are designed to: (1) quantify the deviatoric (shear) behavior of consolidating crushed salt; (2) quantify effects of brine-saturation on consolidation; (3) bolster the data base for crushed salt permeability as a function of crushed salt density; (4) provide a data base for mechanistic modeling of consolidation; (5) provide a data base for defining specifications for WIPP crushed salt seal materials.

Reference designs for all shafts, including dimensions, are given in Figure 6.

More data on the deviatoric (shear) behavior of WIPP crushed salt are needed for definitive calculations of density distributions in full-scale seal components during reconsolidation by creep closure. Laboratory data will be used to formulate an appropriate constitutive model, and numerical calculations of density will be carried out. Assessments of the chemical compatibility of reconsolidating WIPP crushed salt with waste and other repository components are also planned.

4. UPPER SHAFT SEAL SYSTEM

Functional requirements, reference concept, and individual components for the upper shaft seal system are described. The component materials include concrete and bentonite, (see Figuers 5 and 7).

4.1 Upper Shaft Seal System Functional Requirements

The upper shaft seal system will limit groundwater flow from water-bearing zones in the Rustler Formation into lower shafts until the consolidation of crushed salt seal material in the lower shaft is sufficient for sealing effectiveness (i.e., until the crushed salt is consolidated to 95% of intact host rock salt density).

The current reference upper limit on groundwater inflow is 1 m^3 per year (Nowak and Stormont, 1987; Stormont and Arguello, 1988; Stormont, 1988). That reference value may be unnecessarily low, because it was based on an assumption that inflowing groundwater inhibits crushed salt reconsolidation. Preliminary results from recent laboratory tests do not confirm that inhibition. The upper shaft will be sealed by reestablishing the low vertical permeabilities of portions of the Rustler Formation between the water-bearing zones and the Salado Formation.

Seals are required to preserve regional water quality by preventing groundwater flow between the Culebra and Magenta water-bearing strata through WIPP shafts. These seals are described in Figure 4.

4.2 Upper Shaft Seal System Reference Concept

Swelling clay material such as bentonite is the reference primary seal component that impedes water flow. In the reference configuration, clay material is confined by concrete bulkheads. Shaft liners are to be removed before emplacement of the upper shaft seal system.

4.3 Upper Shaft Seal Concrete Components

Upper shaft seal concrete components are located in the Rustler Formation between the bottom of the water-bearing zones and the top of the Salado Formation. Their relative locations within the shaft seal system are shown in Figure 3. They are described in more detail in Figure 5. The major role of these concrete components is containment of the swelling clay components between them.

Reference physical dimensions (Stormont, 1988) have been derived from concrete seal length criteria (Garrett and Pitt, 1958; and 1961) and numerical analyses (Van Sambeek, 1987). The reference length is

10 m, and keyways are envisioned to support axial loads from the mass of the concrete, clay swelling pressures, consolidation of crushed salt, and pressures from potential gas generation in the waste disposal area. Possible concrete shapes have been presented (Stormont, 1988), and alternative reference shapes are shown in Figure 10. Reference designs for all shafts, including dimensions, are given in Figure 6. The definition of shapes (e.g., keyways, tapers, and curves) continues to be refined using numerical models and other analyses.

The reference concrete formulation for upper shaft seal components located in the Rustler Formation (Gulick and Wakeley, 1989) is given in Table 3.

Table 3. Reference Concrete Formulation for Upper Shaft Seals.

Material	Proportion (wt%)
Fine local (Carslbad, NM) aggregate	~35
Coarse local (Carlsbad, NM) aggregate	~35
BCT-1FF grout	~30

The reference BCT-1FF grout, developed specifically for WIPP applications above the Salado Formation, has been extensively characterized (Gulick and Wakeley, 1989). The grout exhibits low heat evolution, durability, high density, low permeability, and desirable but not essential high expansion. It is prepared with the formulation given in Table 4.

Table 4. Reference BCT-1FF Grout

Material	Proportion (wt%)
Class H Cement	53.1
Class C Fly Ash	18.1
Cal Seal (Plaster)	6.5
Dispersant	0.68
Defoamer	0.02
Water	21.6

Concrete seal components in the Salado Formation will consist of the same concrete to be used for lower shaft seal components (see Table 1).

Concrete formulation is continuing. Similarly, the mechanical stability of concrete components continues to be addressed via calculations. Curing and stress analyses are planned for emplacements in host rock salt.

Laboratory tests and literature reviews are planned to assess the chemical stability of concrete and concrete compatibility with brackish

Rustler Formation water, WIPP upper shaft host rocks (particularly anhydrite), swelling clay materials, and the contents of waste disposal rooms.

The feasibility of emplacing concrete components in vertical WIPP excavations has been demonstrated by emplacements of several small-scale (1 m diameter, 1 m long) concrete bulkheads in vertical boreholes underground (Stormont, 1986). A local concrete supplier and typical industrial concrete-handling equipment were employed. The performance of these emplacements was verified, because equivalent permeabilities on the order of 10^{-19} to 10^{-20} m^2 were measured (Peterson et al., 1987). Large-scale in situ tests applicable to shaft seals are being planned.

4.4 Upper Shaft Seal Swelling Clay Components

Swelling clay (e.g., bentonite) components will be located in the shafts within the Rustler Formation between the bottom of the water-bearing zones and the top of the Salado Formation. Their locations within the entire shaft seal system are shown in Figure 3. They are described in more detail in Figure 6.

Low permeability and swelling upon uptake of water are well known properties of smectite-containing clay materials such as bentonite. These properties have been studied extensively for application to the isolation of radioactive waste (Coons et al., 1987). Calculations show that a single bentonite seal of 4 m minimum length can sufficiently reduce water flow from overlying strata to protect underlying crushed salt from saturation (Stormont and Arguello, 1988).

The reference minimum length of 4 m for the swelling clay components was derived from empirical length requirements for clay seals (Stormont, 1988; National Coal Board, 1982). The reference shape is cylindrical. Reference designs for all shafts, including dimensions, are given in Figure 6.

The swelling clay is expected to remain stable and effective for much longer than 100 years. Clays exist naturally in geologic formations, including bedded salt. Evidence for the effectiveness of clay as a sealant for more than 2,000 years has been reported (Lee, 1985). The transformation of smectite to nonswelling minerals, although possible, is expected to be very slow at WIPP ambient temperatures (Meyer and Howard, 1983). Experiments in WIPP-specific brines (Krumhansl, 1984) showed that bentonite should remain effective in the WIPP for much longer than 100 years.

The initial density of the emplaced swelling clay will be tailored to swelling pressure requirements and the limits imposed by local lithostatic pressure and concrete retaining structures. The chemical compatibility of swelling clay materials such as bentonite with reference concrete, Rustler Formation rocks, and Rustler Formation and Salado Formation groundwaters will be assessed.

5. DRIFT AND PANEL SEAL SYSTEM

Functional requirements, reference concept, and individual components for the drift and panel seal system are described. The component materials include concrete and crushed salt (see Figure 9).

5.1 Drift and Panel Seal System Functional Requirements

Over the long term, the drift and panel seals are required to return an interval within the drift to a state of permeability to fluids comparable to the permeability of undisturbed host rock salt. Thus, the drift and panel seals become fluid flow barriers functionally equivalent to the host rock. Within a few months after emplacement, short-term components of the drift and panel seals will function as redundant barriers to the intrusion of water from the upper water-bearing zones in the Rustler Formation and to the flow of gases from the waste disposal area. This short-term seal function is necessary until the long-term functional state of the seal system has been reached by the reconsolidation of emplaced crushed salt due to creep closure of the shaft walls (in fewer than 100 years).

5.2 Drift and Panel Seal System Reference Concept

Reconsolidating crushed WIPP salt primary seals are confined and protected by concrete bulkheads and by the surrounding intact rock until sufficient reconsolidation has been achieved. The concrete components are also designed to resist the flow of gases. Nearby interbeds affected by the DRZ will be sealed with special materials such as grouts. The DRZ in the salt is expected to resist flow initially and be sealed by creep closure. Therefore, the overall flow resistance at the concrete component locations is expected to be effective for attenuating gas pressures along the flow paths.

Drift and panel seals are to be located in the entrances to the waste disposal panels and in the four long north-south access drifts as shown in Figure 8. Seals in the entrances to the panels isolate panels of disposal rooms from each other and offer redundant barriers between the waste in these panels and the WIPP shafts. The seals in the northernmost portions of the four access drifts isolate the waste disposal area from the shafts.

The reference concept and design of the drift and panel seal components are similar to those for the lower seal system. One difference is that the reference short-term composite drift and panel seals do not include swelling clay material. Swelling clay may be considered as an option later.

5.3 Drift and Panel Seal Concrete Components

Concrete drift and panel seal components will be end-members that confine preconsolidated crushed salt, the long-term seal material. Their locations within the system of WIPP drifts and panels are shown in Figure 8. They are described in more detail in Figure 9.

Containment of the preconsolidated crushed salt and resistance to fluid flow are the major roles of the concrete components. Equivalent permeabilities of the order of 10^{-19} to 10^{-20} m^2 have been measured for concrete emplacements in the Salado host rock (Peterson et al., 1987).

Reference length dimensions (Stormont, 1988) have been derived from concrete seal length criteria (Garrett and Pitt, 1958; and 1961). The reference length is 10 m, and keyways are envisioned to support axial loads from the pressure of potential gas generation in the waste disposal area containment of consolidating crushed salt. Possible concrete shapes have been presented (Stormont, 1988), and alternative reference shapes are shown in Figure 10. Reference designs for all panels and drift seals, including dimensions, are given in Figure 9. The definition of shapes (e.g., keyways, tapers, and curves) continues to be refined using numerical models and other analyses.

The reference concrete formulation for drift and panel seals (Gulick and Wakeley, 1989) is given in Table 5.

Table 5. Reference Concrete Formulation for Drift and Panel Seals.

Material	Proportion (wt%)
Fine local (Carslbad, NM) aggregate	~35
Coarse local (Carlsbad, NM) aggregate	~35
BCT-1F grout	~30

The reference BCT-1F salt-saturated grout, developed specifically for WIPP applications in the Salado Formation, has been extensively characterized (Gulick and Wakeley, 1989). The grout exhibits low heat evolution, durability, high density, low permeability, and desirable but not essential high expansion. It is prepared with the formulation given in Table 6.

Concrete formulation is continuing. The mechanical stability of concrete components of panel and drift seals was shown by numerical analyses (Arguello and Torres, 1987). No tensile stresses were found in the modeled concrete component, and preexisting tensile stresses in the host rock salt were predicted to disappear and become compressive soon after seal emplacement (Stormont, 1988). The mechanical stability of concrete components continues calculations. Curing and stress analyses are planned for emplacements in salt.

Table 6. Reference BCT-1F Salt-Saturated Grout

Material	Proportion (wt%)
Class H Cement	48.3
Class C Fly Ash	16.2
Cal Seal (Plaster)	5.7
Sodium Chloride (NaCl)	7.9
Dispersant	0.7
Defoamer	0.02
Water	21.1

Initial results from tests and literature reviews (Stormont, 1986; Stormont and Howard, 1986; Wakeley, 1989;) support the expectation that grouts and concretes will be stable in halite and in brines that have a high sodium chloride content. The chemical stability of concrete and concrete compatibility with WIPP brines, WIPP salt, swelling clay, and the contents of waste disposal rooms continue to be assessed.

The feasibility of emplacing concrete components in horizontal WIPP excavations has been demonstrated by emplacements of small scale (1 m diameter, 1 m long) concrete bulkheads in horizontal boreholes underground (Stormont and Howard, 1986). A local concrete supplier and typical industrial concrete-handling equipment were employed. The performance of these emplacements was verified, because equivalent permeabilities on the order of 10^{-19} to 10^{-20} m^2 (Peterson et al., 1987) were measured. Large-scale in situ tests applicable to shaft seals are being planned.

5.4 Drift and Panel Seal Crushed Salt Components

The general locations of these components are shown in Figure 8. The reference design is shown in Figure 9. Crushed WIPP salt will be tamped in the locations shown up to the point at which sufficient overhead for emplacing and tamping is no longer available. The remaining volume will be filled with preconsolidated crushed salt blocks.

The crushed salt is intended to have a reference initial density equal to 80% of the density of intact WIPP host rock salt (80% relative density). That initial state will be achieved by pouring and tamping crushed salt and by laying preconsolidated salt blocks. The feasibility of manufacturing crushed WIPP salt blocks with 80% relative density has been shown (Stormont and Howard, 1987). Creep closure of the drifts will continue to consolidate this crushed salt.

Numerical analysis of the consolidation a 20 m-long crushed salt emplacement between concrete bulkheads in a hypothetical panel seal (Arguello, 1988) predicted that 95% relative density will be reached in the central core well within 100 years. The permeability of the reconsolidated salt is expected to be 1×10^{-20} m^2, with an expected range of 3×10^{-21} to 3×10^{-20} m^2 (Lappin et al., 1989).

Ongoing laboratory studies of WIPP crushed salt consolidation are designed to: (1) quantify the deviatoric (shear) behavior of consolidating crushed salt; (2) quantify effects of brine-saturation on consolidation; (3) bolster the data base for crushed salt permeability as a function of crushed salt density; (4) provide a data base for mechanistic modeling of consolidation; (5) provide a data base to define specifications for WIPP crushed salt seal materials. More data on the deviatoric behavior of WIPP crushed salt are needed for definitive calculations of density distributions in full-scale seal components during reconsolidation by creep closure. Laboratory data will be used to formulate an appropriate constitutive model, and numerical calculations of density will be carried out. Assessments of the compatibility of reconsolidating WIPP crushed salt with waste and other repository materials are planned.

6. APPLICABLE INFORMATION FROM OTHER WASTE MANAGEMENT PROGRAMS

The WIPP sealing program has been developed in parallel with other national and international programs for sealing nuclear waste repositories in salt formations. WIPP design concepts, materials, technical issues, and proposed methods of emplacement are therefore similar to those of other programs. For example, the design concepts for WIPP seals are similar to those proposed by Kelsall et al. (1985a, and 1985b) for bedded salt repositories in the Paradox and Permian Basins. Similarly, techniques for developing candidate concrete mixtures are almost identical to those described by Buck (1985) for a high-level waste repository. Bentonite components have been studied extensively in the Swedish and Canadian nuclear waste disposal programs. Finally, international programs in France, the Federal Republic of Germany (FRG), and the Netherlands generally use multicomponent seals with various combinations of crushed salt, bitumen, and concrete components (Jehan and Raynal, 1989; Prij and Vons, 1989; Engelman et al., 1989). Much of the pertinent information from the international program is summarized below.

6.1 Crushed Salt

Analyses of crushed salt behavior are being performed in the FRG to develop and support constitutive models for the thermomechanical study of the interaction between the salt rock and crushed salt backfill in a high-level waste repository. Laboratory and in situ experiments demonstrated that creep of the host rock had a significant effect on the consolidation of the crushed salt backfill, whereas the backpressure of the crushed salt backfill on the host rock was negligible (Ghoreychi et al., 1989).

Full-scale in situ testing programs to investigate crushed salt consolidation are being designed, developed, and initiated at the Asse salt mine in the FRG (Bechthold et al., 1989; Engelmann et al., 1989). Thermal conditions relevant to a spent fuel repository will be simulated. The planned experiments are designed to provide data on backfill and host rock behavior. Backfill material is to be crushed salt. Part of the instrumentation program will determine the following information (Bechthold et al., 1989): temperature in the crushed salt backfill, backfill density and compaction, and permeability of the crushed salt backfill.

Another full-scale in situ test is being planned to investigate the long-term sealing effectiveness of crushed salt and other seal materials and to demonstrate the technical feasibility of tight sealing against elevated gas and fluid pressures. A test dam (bulkhead) consisting of several seal components is to be built in the Asse salt mine. The multiple-prism-shaped sealing system will consist primarily of an abutment of salt-saturated concrete, a long-term seal component composed of compacted briquettes of crushed salt, and various other sealing materials (e.g., asphalt). The test program will compare measured in situ permeabilities with long-term predictions (Engelmann et al., 1989).

Other in situ tests and investigations at the Asse salt mine include the compression behavior of rock salt grit, the permeability of emplaced backfill, and the examination of a 60-year old backfilled chamber (Kappei, 1987). The old backfilled section has already undergone considerable consolidation. Cores were obtained and examined for density, pore volume, permeability, and unconfined compressive and tensile strength. In addition, laboratory and field load consolidation studies showed that reconsolidation can be more readily achieved if the initial bulk density has reached a high degree of compaction before installation (Kappei, 1987). Investigations of the consolidation behavior of crushed salt when brine is added have also been initiated (Kappei, 1987). Early results indicate that the final compression increases with increasing moisture content when starting with the same initial bulk density.

6.2 Concrete

Studies show that a concrete component possessing high chemical durability can be formulated, and fabrication methods can be developed to yield a high-density, high-strength concrete component that provides an effective barrier for times longer than 100 years (Heimann et al., 1986). However, laboratory studies have indicated that the presence of clay accelerates the rate of dissolution of some cements (Heimann et al., 1986). The longevity of concrete was evaluated in a report by Malinowski (1981). The evaluation of some cementitious materials revealed that they had survived in apparently good condition for centuries.

A test dam of salt-saturated concrete components and components of other seal materials will be built in the Asse salt mine.

Several cross-sectional concrete seal designs have been evaluated structurally for sealing off cavities in potash and rock salt mines (Sitz, 1984). Calculations were performed on several designs to predict tensile stresses, fractures in the seal or rock, etc. Several different types of concrete have been structurally evaluated for seal tightness. Newly developed cross-sectional sealing variants in practical use have, thus far, been successful (Sitz, 1984).

6.3 Swelling Clay

A major ongoing program that supports the use of Na bentonite as a sealing component is the Stripa Project in Sweden (Pusch, 1987). The

Stripa Project has a very comprehensive bentonite study, including laboratory studies, and small- and large-scale in situ tests. Laboratory and in situ testing demonstrated the ability of bentonite to absorb water and swell. Swelling causes the saturated bentonite to expand into openings to be sealed (Pusch, 1980, and 1987; Pusch et al., 1987). Laboratory studies indicated that highly compacted confined bentonite could develop swelling pressures as high as 50 MPa (Pusch, 1980). In addition, it was determined that swelling pressure can be controlled by controlling the bulk density of the clay (Pusch, 1980).

Large-scale in situ tests demonstrated that the slowest and lowest pressure buildups were in portions of the seals where the bentonite was loosely layered (pressures did not exceed 0.1 MPa), while the maximum pressures recorded (0.5 MPa) were where the bentonite was at a higher density. At the rock/bentonite interface, the pressure buildup was irregular, indicating that the saturation and swelling were functions of the fracturing and displacement of the bentonite blocks (Pusch, 1987; Pusch et al., 1987). Laboratory and in situ tests demonstrated that Na bentonite penetrates fractures wider than 0.1 mm (Pusch et al., 1987).

Another investigation was developed to test the potential of erosion as a cause of bentonite loss (Pusch, 1983). Water uptake in dense bentonite produces expansion that results in a tight contact with the confining rock, and the swelling potential leads to a continued expansion of the bentonite into joints and fractures (Pusch, 1983). In situ tests demonstrated that erosion of highly precompacted bentonite in the initial phase is negligible; furthermore, the bentonite that has expanded into rock fractures is not substantially affected.

Major conclusions about the sealing function of highly precompacted, confined bentonite include the following (Pusch, 1987): bentonite swells and makes a tight interface contact with the surrounding host rock, wetting proceeds at the rate predicted by basic diffusion-type models, and bentonite penetrates into visible open fractures and seals them to a depth of a few millimeters.

Another major ongoing program supporting the use of Na bentonite as sealing material is the Canadian Nuclear Fuel Waste Management Program. Gray et al. (1984) and Lopez (1987) evaluated the use of sand/bentonite mixtures for sealing. The Canadian program also recognized the ability of bentonite to swell and heal on exposure to free water; however, it was noted that a very high swelling pressure could be undesirable. Laboratory studies indicated that measured swelling pressures for 100% Na bentonite initially increased linearly and slowly as a function of increasing dry density.

Other laboratory studies evaluated crushed granite/clay mixtures over a range of parameters (mix proportions, moisture content, etc.). Bentonite was significantly more impervious to water migration than other tested clays. Bentonite was also self-healing when dried and rewetted (Radhakrishna and Chan, 1985).

A documented analog the expectation that a properly placed clay sealant can effectively prevent the migration of water and air in a subsurface environment for periods as long as 2,100 years (Lee, 1985).

7. PRINCIPAL ACTIVITIES AND PRODUCTS OF THE SEAL SYSTEM DEVELOPMENT PROGRAM

The principal activities in the sealing program are focused on developing a detailed conceptual design for the seal system and a seal system performance model. Major products of the program, along with program elements such as supporting reports, analyses, designs, and test implementation, are depicted in Figure 1. Also shown by interconnecting lines, arrows, and dates are paths and time sequences of testing and information flow. Descriptions of these products, program elements, and related activities follow. Dates from the Figure are given in parentheses with the related text. For example, the seal system performance model (7/92) is shown in Figure 1 with a completion date of 7/92.

The detailed conceptual design (5/93) will consist of engineering drawings that depict the location, physical dimensions and shapes, sequence of emplacement, and materials to be used for each component of the seal system. Accompanying text will describe seal emplacement/construction, the compositions of specific materials for the seals, and the results of numerical analyses for evaluating numerous features of the design. References will be given for supporting technical reports that document laboratory- and field-test results, emplacement feasibility demonstrations, technical details of mechanical and hydrologic models, seal materials stability and compatibility evaluations, and other relevant material. The detailed designs and performance models (7/92) for the seals will be used as the basis for seal-related performance evaluations in total system performance assessments.

Key testing activities include large-scale seal tests, small-scale seal tests, disturbed rock zone (DRZ) characterization measurements, and brine inflow tests. Descriptions of these activities and their significance follow.

Large-scale in situ tests of selected seal components will be emplaced (beginning 1/92) in excavations in the experimental area of the WIPP. These tests will demonstrate emplacement operations (1/92) and provide data on the short-term performance of the emplacements (6/92, 6/93, 6/94). Results will be used to aid in predicting hydraulic conductivities for gases and liquids in shaft, drift, and panel seals, including associated interbeds and the DRZ. The temporal performance (7/92) of all seal components will be extrapolated from large- and small-scale in situ test data, laboratory data, numerical modeling and analyses, and experience from other facilities and programs (e.g., potash mines and international programs on waste disposal in salt).

Small-scale in situ tests demonstrated the emplacement and initial performance of concrete seal components (1986). Concrete was emplaced in 1 m intervals of 1-m-diameter boreholes that had both horizontally and vertically oriented axes, and initial performance was determined by measurements of fluid flow. The horizontally oriented boreholes were used to demonstrate the pumping of concrete into the space between vertical forms, the operation anticipated to be used for drift and panel seals. The vertically oriented boreholes were used to demonstrate pouring of concrete in a simulated shaft. Good initial performance was measured for emplacements in both orientations.

Small-scale in situ tests in 1-m-diameter boreholes will demonstrate the emplacement of preconsolidated blocks of swelling clay material (bentonite) (1989) and crushed WIPP salt (1989). The initial performance of the emplaced swelling clay blocks will be determined by measurements of brine flow rates through the clay (1/91).

Small-scale in situ tests of emplacement and initial performance of seal components and grouts in interbeds and anhydritic rocks are being planned (6/91). Small-scale tests of multicomponent seals are also being planned.

The development and some fluid flow characteristics of the DRZ around WIPP rooms, drifts, and shafts, including interbeds, have been determined by in situ fluid flow measurements (1988). Laboratory data have shown that the DRZ in predominantly halitic rock is likely to reheal as creep closure restores compressive stress in the rock. Investigations have also shown that interbeds (e.g., Marker Bed 139) may require special sealing techniques such as grouting. Ongoing investigations of the DRZ emphasize the temporal evolution of hydraulic conductivities for gases and liquids in halitic rocks and in interbeds near WIPP excavations (10/90, 8/91, and 1/92).

Models for quantitative predictions of brine transport from the host rock salt into consolidating crushed WIPP salt and for creep closure will be obtained from other WIPP programs. Model development for brine inflow includes elucidation of fluid flow mechanisms and incorporation of heterogeneities in the host rock. In situ measurements will be carried out over several years, and predictions beyond that time frame will be made from mechanistic models for brine transport in the Salado Formation.

8. REFERENCES

Arguello, J. G., and T. M. Torres, 1987, WIPP Panel Entryway Seal - Numerical Simulation of Seal Component/Formation Interaction for Preliminary Seal Design Evaluation, SAND87-2591, Sandia National Laboratories, Albuquerque, New Mexico.

Arguello, J. G., 1988, WIPP Panel Entryway Seal - Numerical Simulation of Seal Composite Interaction for Preliminary Seal Design Evaluation, SAND87-2804, Sandia National Laboratories, Albuquerque, New Mexico.

Bechthold, W., S. Heuserman, C. Schrimpf, and G. E. Gommlich, 1989, "Large-Scale Test on In-Situ Backfill Properties and Behavior Under Reference Repository Conditions," Braunschwerg, Federal Republic of Germany, Sealing of Radioactive Waste Repositories Workshop, May 22-25.

Bertram-Howery, S. G., and R. L. Hunter, Editors, 1989, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, SAND89-0178, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D. J., and J. C. Stormont, 1988, 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, Albuquerque, New Mexico.

Buck, A. D., 1985, Development of Two Candidate Concrete Mixtures (Salt, Nonsalt) for Repository Sealing Applications, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburgh, Mississippi Miscellaneous Paper SL-85-8.

Coons, W., A. Bergstrom, P. Gnirk, M. Gray, B. Knecht, R. Pusch, J. Steadman, B. Stillborg, M. Tokonami, and M. Vaajasaari, 1987, State-of-the-Art Report on Potentially Useful Materials for Sealing Nuclear Waste Repositories, Stripa Project 87-12, Swedish Nuclear Fuel and Waste Management Company, Stockholm, Sweden.

Engelmann, H. J., P. W. Boochs, W. Hansel, and L. Peters, 1989, "Dams As Sealing Systems in Rock Salt Formations -- Test Dam Construction and Determination of Permeability," Braunschwerg, Federal Republic of Germany, Sealing of Radioactive Waste Repositories Workshop, May 22-25.

Garrett, W. S., and L. T. Campbell Pitt, 1958, Tests on Experimental Bulkheads for High Pressures, Journal of South African Institute of Mining and Metallurgy, 59:123-143.

Garrett, W. S., and L. T. Campbell Pitt, 1961, Design and Construction of Underground Bulkheads and Water Barriers, III, Transactions of the Seventh Commonwealth Mining and Metallurgy Congress, South African Institute of Mining and Metallurgy.

Ghoreychi, M., P. Berest, B. Bazargan-Sabet, and J. Roman, 1989, "Thermomechanical Study of Interaction Between Rocksalt and Crushed Salt," Braunschwerg, Federal Republic of Germany, Sealing of Radioactive Waste Repositories Workshop, May 22-25.

Gray, M. N., S. C. H. Cheung, and D. A. Dixon, 1984, The Influence of Sand Content on Swelling Pressures and Structure Developed in Statistically Compacted Na-Bentonite, AECL-7825, Atomic Energy of Canada Limited, Pinawa Manitoba, September.

Gulick, C. W., and L. D. Wakeley, 1989, Reference Properties of Cement-Based Plugging and Sealing Materials for the Waste Isolation Pilot Plant (WIPP), SL-89-17, Department of the Army, Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Heimann, R. B., M. A. T. Stanchell, and R. D. Hooton, 1986, Short-Term Dissolution Experiments on Various Cement Formulations in Standard Canadian Shield Saline Solution in the Presence of Clay, AECL-9059, Atomic Energy of Canada Limited, December.

Holcomb, D. J., and M. Shields, 1987, Hydrostatic Creep consolidation of Crushed Salt with Added Water, SAND87-1990, Sandia National Laboratories, Albuquerque, New Mexico.

Hunter, R. L., 1989, Events and Processes for Constructing Scenarios for the Release of Transuranic Waste from the Waste Isolation Pilot Plant, Southeastern New Mexico, SAND89-2546, Sandia National Laboratories, Albuquerque, New Mexico.

Jehan, R. A., and M. Raynal, 1989, "Repository Sealing in Salt Formations, French Programme and Criteria," in Sealing of Radioactive Waste Repositories, Braunschweig, Federal Republic of Germany.

Kappei, G., 1987, Geotechnical Investigations on Backfill Materials in the ASSE Salt Mine, GSF T-250, Institut f r Tieflagerung.

Kelsall, P. C., D. Meyer, J. B. Case and W. E. Coons, 1985a, Schematic Designs for Penetration Seals for a Repository in the Paradox Basin, BMI/ONWI-563, Office of Nuclear Waste Isolation, Columbus, Ohio.

Kelsall, P. C., J. B. Case, W. E. Coons, J. G. Franzone, and D. Meyer, 1985b, Schematic Designs for Penetration Seals for a Repository in the Permian Basin, BMI/ONWI-564, Office of Nuclear Waste Isolation, Columbus, Ohio.

Krumhansl, J. L., 1984, Observations Regarding the Stability of Bentonite Backfill in a High-Level Waste (HLW) Repository in Rock Salt, SAND83-1293, Sandia National Laboratories, Albuquerque, New Mexico.

Lappin, A. R., R. L. Hunter, Editors; D. P. Garber and P. B. Davies, Associate Editors, 1989, Systems Analysis, Long-Term Radionuclide Transport, and Dose Asssessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989, SAND89-0462, Sandia National Laboratories, Albuquerque, New Mexico.

Lee, C. F., 1985, A Case History on Long-Term Effectiveness of Clay Sealant, TR-338, Atomic Energy of Canada Limited, June.

Lopez, R. S., Editor, 1987, The Vault Sealing Program: Proceedings of the Workshop Held 1983 December 1-2 in Toronto, Ontario, TR-339, Atomic Energy of Canada Limited.

Malinowski, R., 1981, Ancient Mortars and Concretes- Durability Aspects, Goteberg, Sweden.

Meyer, D., and J. J. Howard, Editors, 1983, Evaluation of Clays and Clay Minerals for Application to Repository Sealing, ONWI-486, Office of Nuclear Waste Isolation.

National Coal Board, 1982, The Treatment of Disused Mine Shafts and Adits, Mining Department, National Coal Board.

Nowak, E. J., and J. C. Stormont, 1987, Scoping Model Calculations of the Reconsolidation of Crushed Salt in WIPP Shafts, SAND87-0879, Sandia National Laboratories, Albuquerque, New Mexico.

Nowak, E. J., D. F. McTigue, and R. Beraun, 1988, Brine Inflow to WIPP Disposal Rooms: Data, Modeling, and Assessment, SAND88-0112, Sandia National Laboratories, Albuquerque, New Mexico.

Peterson, E. W., P. L. Lagus, and K. Lie, 1987, Fluid Flow Measurements of Test Series A and B for the Small Scale Seal Performance Tests, SAND87-7041, Sandia National Laboratories, Albuquerque, New Mexico.

Prij, J., and L. H. Vons, 1989, "The Role of Dams and Seals on the Release of Nuclides Due to Water Intrusion into the Repository," in Sealing of Radioactive Waste Repositories, Braunschweig, Federal Republic of Germany.

Pusch, R., 1980, Swelling Pressure of Highly Compacted Bentonite, KBS80-13, Stockholm.

Pusch, R., 1983, Stability of Bentonite Gels in Crystalline Rock--Physical Aspects, Stripa Project Report 83-04.

Pusch, R., 1987, Workshop on Sealing Techniques, Tested in the Stripa Project and Being of General Potential Use of Rock Sealing, Stripa Project Report 87-05, February.

Pusch, R., L. Borgesson, and G. Ranquist, 1987, Final Report of the Borehole, Shaft, and Tunnel Sealing Test--Volume II: Shaft Plugging, Stripa Project Report 87-02, February.

Radhakrishna, H. S., and H. T. Chan, 1985, Strength and Hydraulic Conductivity of Clay-Based Buffers for a Deep Underground Nuclear Fuel Waste Disposal Vault, TR-327, Atomic Energy of Canada Limited, June.

Sitz, P., 1984, Cross-Section Seals of Underground Cavities Involving Dams and Plugs, RS3140/84/046, Bergakademie Freiberg, GDR, May.

Sjaardema, G. D. and R. D. Krieg, 1987, A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations, SAND87-1977, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., 1984, Plugging and Sealing Program for the Waste Isolation Pilot Plant (WIPP), SAND84-1057, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., Editor, 1986, Development and Implementation: Test Series A of the Small-Scale Seal Performance Tests, SAND85-2602, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., and C. L. Howard, 1986, Development and Implementation: Test Series B of the Small-Scale Seal Performance Tests, SAND86-1329, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., and C. L. Howard, 1987, Development, Implementation and Early Results: Test Series C of the Small-Scale Seal Performance Tests, SAND87-2203, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., 1988, Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant, SAND87-3083, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., and J. G. Arguello, 1988, Model Calculations of Flow through Shaft Seals in the Rustler Formation, SAND87-2859, Sandia National Laboratories, Albuquerque, New Mexico.

Tyler, L. D., R. V. Matalucci, M. A. Molecke, D. E. Munson, E. J. Nowak, and J. C. Stormont, 1988, Summary Report for the WIPP Technology Development Program for Isolation of Radioactive Waste, SAND88-0844, Sandia National Laboratories, Albuquerque, New Mexico.

United States Department of Energy, 1989, Draft Final Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment, DOE/WIPP 89-011, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Van Sambeek, L. L., 1987, Thermal and Thermomechanical Analyses of WIPP Shaft Seals, SAND87-7039, Sandia National Laboratories, Albuquerque, New Mexico.

Wakeley, L. D., 1989, Durability of a Chloride-Saturated Concrete for Sealing Radioactive Wastes in Bedded Rock Salt, SP-100-34, Waterways Experiment Station, Vicksburg MS, in: "Concrete Durability, Katherine and Bryant Mather International Conference, J. M. Scanlon, ed., Volume 1, American Concrete Institute, Detroit MI.

APPENDIX A

GLOSSARY OF PRINCIPAL SEAL-SPECIFIC TERMS

The principal seal-specific terms used in this report are defined below to aid understanding of the drawings and the text of this report.

Design Basis - Specific design requirements and parameters for a seal design task that have been derived from the design criteria; the design basis is a translation of design criteria into the specifics for a particular seal component or system to assure that it will satisfy the criteria.

Design Concepts - Generalized descriptions of shapes, materials, locations, and functions of seal components (usually depicted in undimensioned sketches); the feasibility of a concept is evaluated before proceeding to a more detailed design.

Design Criteria - Requirements, characteristics, performance goals, and general standards for the design of seal systems and components, i.e., the standards against which the design will be evaluated; the design basis is derived from the design criteria.

Design Methodology - The approaches, techniques, mathematical relationships, models, and values for conditions and properties that have been chosen to be used uniformly throughout the seal design process by all participants; an accepted design methodology assures uniformity and comparability among all design calculations, options, and decisions.

Design Options - Alternative design specifics or approaches that conform to the design methodology and satisfy the design criteria.

Detailed Conceptual Design - Design drawings and associated materials specifications, equipment identification, sequence of operations, etc., for all seal components. The design is intended to provide sufficient detail to establish emplacement feasibility and to serve as the basis for performance assessments related to regulatory compliance evaluations. The design will be described in a design report that will be published in FY93.

Disturbed Rock Zone (DRZ) - The volume of rock in which mechanical properties and hydrologic properties have changed significantly in response to an excavation. The DRZ near a seal may impact the performance of the seal.

Drift Block - Those portions of drifts that are bounded by a specified set of drift and/or panel seals.

Drift Seals - Multicomponent seals placed in underground drifts.

Functions - The purposes for which seal components are intended; these include considerations of brine and/or gas flow, duration of the needed performance, etc.

Large-Scale Seal Tests - In situ tests planned to demonstrate, on a full-scale or nearly full-scale, the emplacement feasibility and the post-emplacement performance of selected seal components.

Long-Term Seal - A set of seal components consisting of preconsolidated salt emplaced within the Salado Formation and intended to function as a principal, post-closure barrier to fluid flow; the low hydraulic conductivity is achieved by consolidation to a permeability state approaching that of the original WIPP host rock salt.

Panel Seals - Multicomponent drift seals placed in the access or egress drifts that serve the waste emplacement panels.

Reference Configuration - A set of seal designs (drawings, materials specifications, equipment, etc.) that form the current referenceable basis for use in evaluations of seal system performance and for interfaces with other organizations (repository operations, regulators, etc.).

Seal Component - One of the distinct elements of a composite seal, having a defined function and generally identified by the principal material used in its construction, e.g., concrete, bentonite, or crushed salt.

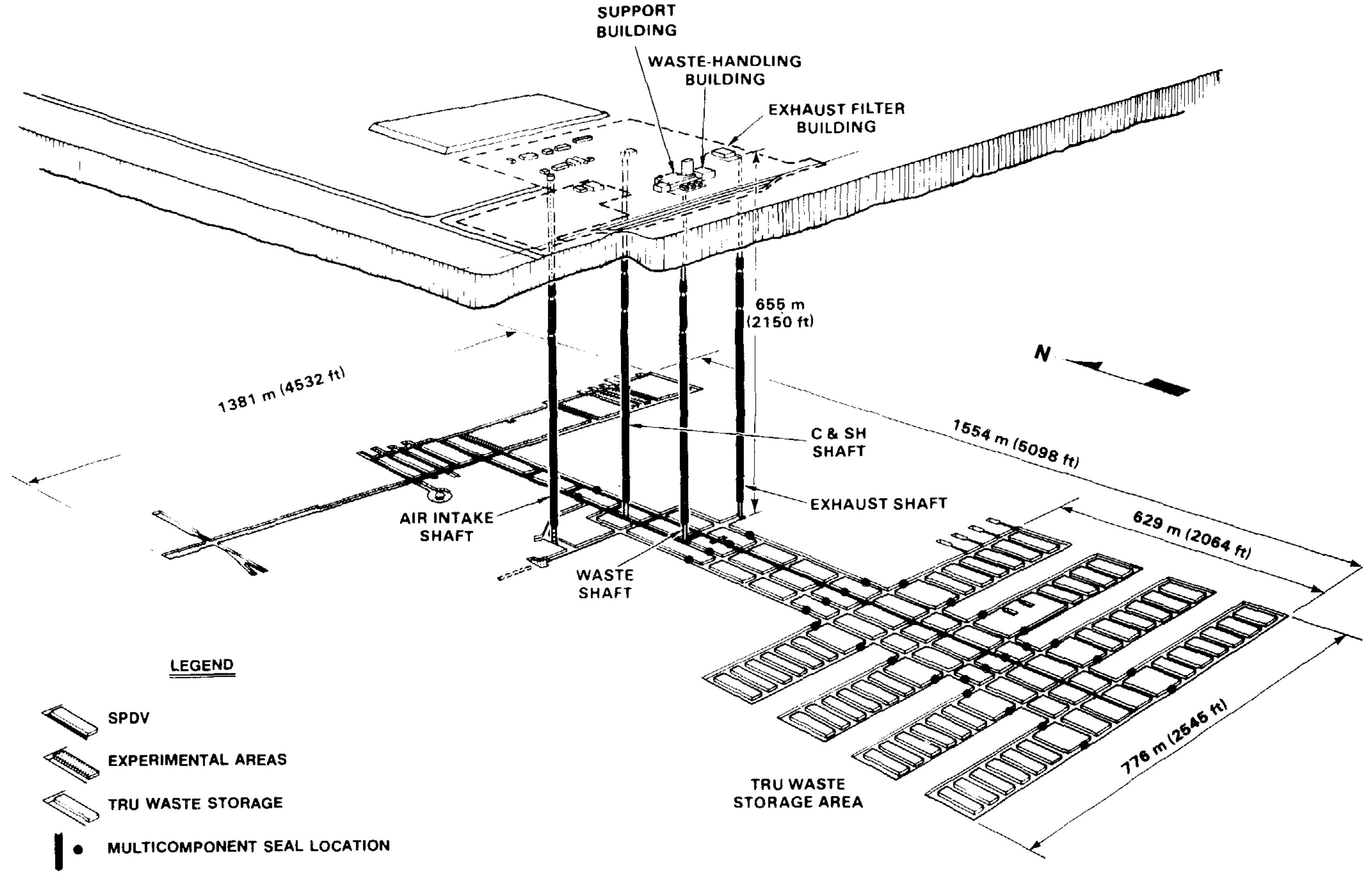
Seal System - The assemblage of engineered barriers, to be ultimately emplaced in shafts, drifts and their associated disturbed rock zones, designed to limit fluid flow to and from the repository for the purpose of meeting regulatory requirements.

Shaft Seals - Multicomponent seals placed in the four shafts that provide access to the WIPP repository horizon.

Short-Term Seal - A set of seal components (e.g., concrete, bentonite) that are required to perform for a period of approximately 100 years to assure that the long-term components can begin to function as designed.

Small-Scale Seal Performance Tests - A series of in situ tests, currently being conducted in approximately 1-meter diameter boreholes, designed to demonstrate the emplacement feasibility of shaft and drift seal components in both horizontal and vertical excavations and to measure post-emplacement seal material performance.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



ABBREVIATIONS

SPDV - SITE & PRELIMINARY DESIGN VALIDATION

C & SH - CONSTRUCTION & SALT HANDLING

SNL APPROVALS					
ORG	DATE	APPROVALS			
6314	11 22 89			DR C. NORTHROP	
〃	11/22/89			CHK D.L. PULLIAM 11/21/89	
6346	11-28-89	J.M. Torres		ENG R. JONES 11/21/89	
6346	11/28/89	Joe R Tillerson		APVD 11/22/89	
			NEXT ASSEMBLY		
			APPLICATION		

Sandia National Laboratories

TITLE
WIPP FACILITY
SEAL ARRANGEMENT

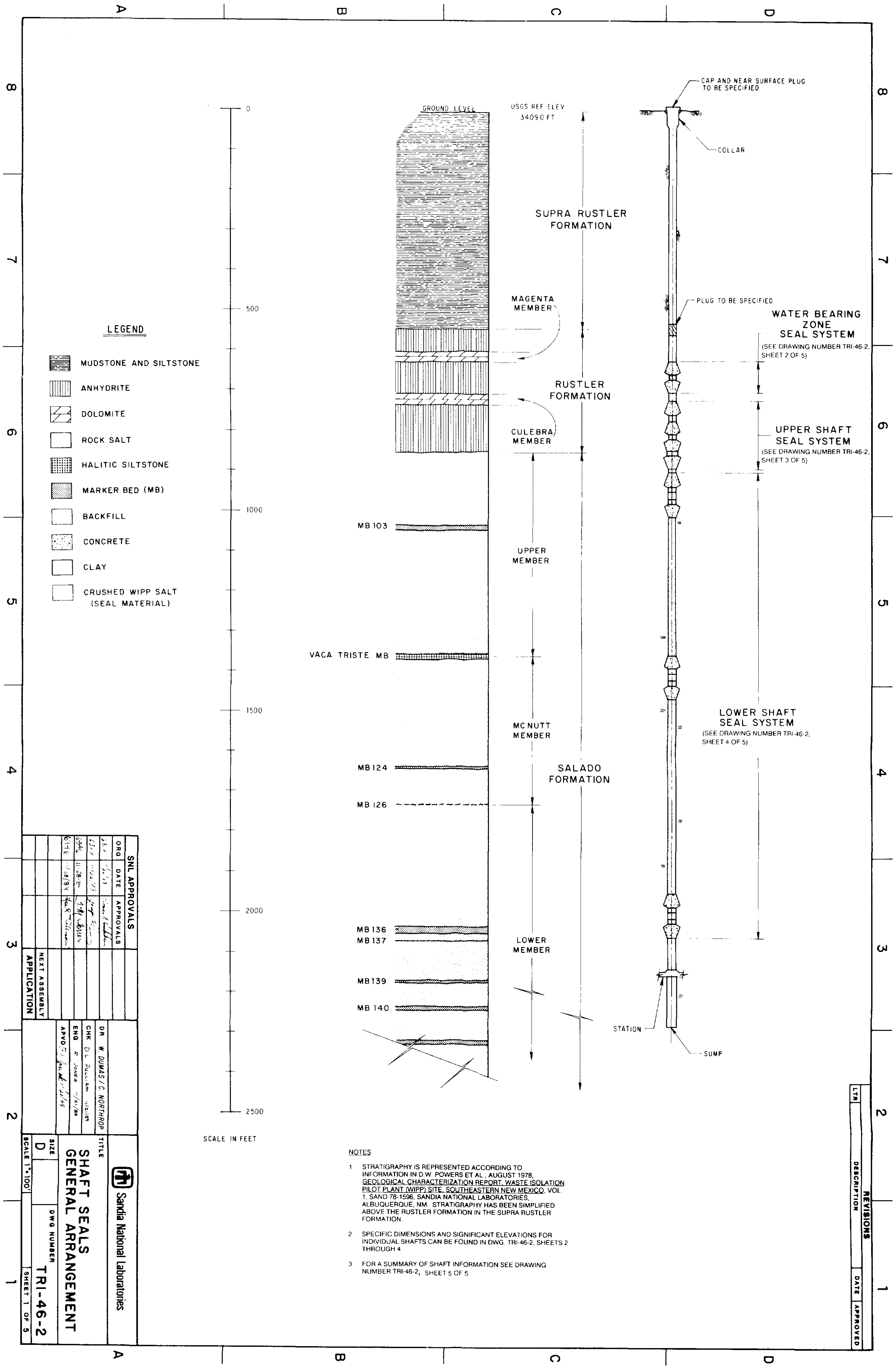
SIZE D

DWG NUMBER TRI-46-1

SCALE NONE

SHEET 1 OF 1

Fig. 2. WIPP Facility Seal Arrangement



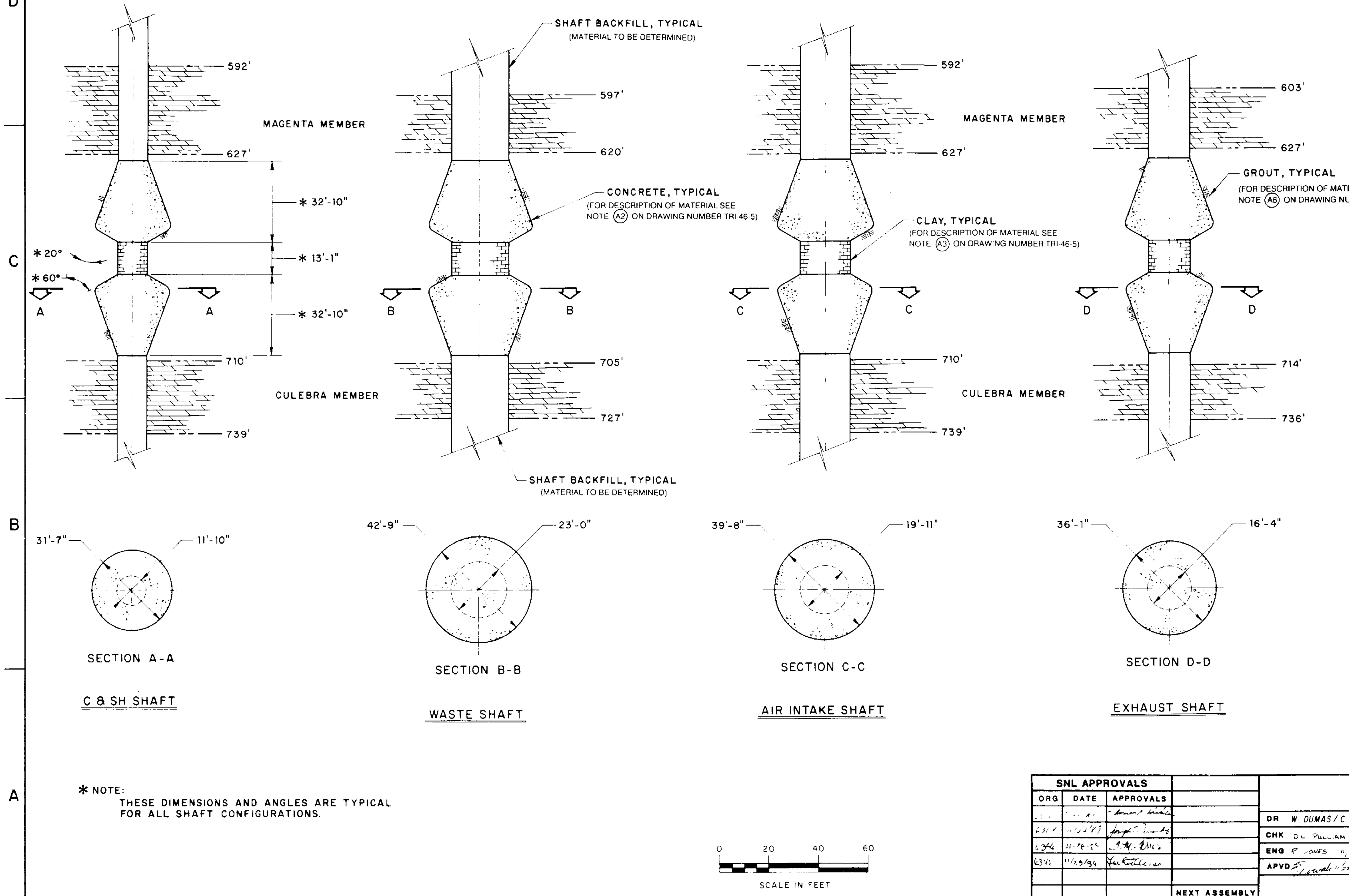
NOTES

1 STRATIGRAPHY IS REPRESENTED ACCORDING TO INFORMATION IN D.W. POWERS ET AL., AUGUST 1978, GEOLOGICAL CHARACTERIZATION REPORT, WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO, VOL. 1, SAND 78-1596, SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM. STRATIGRAPHY HAS BEEN SIMPLIFIED ABOVE THE RUSTLER FORMATION IN THE SUPRA RUSTLER FORMATION.

2 SPECIFIC DIMENSIONS AND SIGNIFICANT ELEVATIONS FOR INDIVIDUAL SHAFTS CAN BE FOUND IN DWG. TRI-46-2, SHEETS 2 THROUGH 4

3 FOR A SUMMARY OF SHAFT INFORMATION SEE DRAWING NUMBER TRI-46-2, SHEET 5 OF 5.

Fig. 3. Shaft Seals General Arrangement



* NOTE:
THESE DIMENSIONS AND ANGLES ARE TYPICAL FOR ALL SHAFT CONFIGURATIONS.

NOTES

1. DEPTH MEASUREMENTS INDICATE NUMBER OF FEET BELOW THE SURFACE, WHERE THE SURFACE EQUALS 0'-0". THE SURFACE ELEVATION THAT IS USED AS THE REFERENCE IS 3,409'-0" (USGS 1927 NORTH AMERICAN DATUM).
2. ALL STRATIGRAPHIC FEATURES ARE REPRESENTED ACCORDING TO DATA COMPILED FROM U.S. DEPARTMENT OF ENERGY, OCTOBER 1986, WIPP DESIGN VALIDATION FINAL REPORT, DOE-WIPP-86-010, BECHTEL NATIONAL INC., SAN FRANCISCO, CA.
3. THE WATER BEARING ZONE SEAL SYSTEM IS TO BE CONSTRUCTED AT A DEPTH WHERE THE SEAL IS CENTERED BETWEEN THE TWO WATER-BEARING MEMBERS.
4. ALL SHAFT DRAWINGS REPRESENT EXCAVATED DIAMETERS (I.E., WITHOUT LINERS) FOR BOTH EXISTING AND PLANNED CONSTRUCTION. LINERS MUST BE REMOVED BEFORE SEAL EMPLACEMENT.
5. SHAFT DIAMETERS ARE REPRESENTED ACCORDING TO INFORMATION OBTAINED FROM THE FOLLOWING DRAWING SETS:
   - A. WASTE SHAFT. US DOE/WIPP DRAWING 31-R-013-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 31-R-002-OID (WESTINGHOUSE, CARLSBAD, NM).
   - B. AIR INTAKE SHAFT. US DOE/WIPP DRAWING 33-R-001-34A (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 33-R-029-34A (BECHTEL, SAN FRANCISCO, CA).
   - C. EXHAUST SHAFT. US DOE/WIPP DRAWING 35-R-001-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 35-R-002-OID (BECHTEL, SAN FRANCISCO, CA).
   - D. *EXPLORATORY SHAFT. US DOE/WIPP DRAWING 37-R-010 (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 37-R-012 (BECHTEL, SAN FRANCISCO, CA).

*EXPLORATORY SHAFT HAS SINCE BEEN CHANGED TO CONSTRUCTION & SALT HANDLING SHAFT.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

SNL APPROVALS		
ORG	DATE	APPROVALS
[illegible]	[illegible]	[illegible]
6314	[illegible]	[illegible]
6346	11-28-89	[illegible]
6346	11/29/89	[illegible]

NEXT ASSEMBLY
APPLICATION

DR W DUMAS / C. NORTHROP
CHK DL PULLIAM 11/21/89
ENG R JONES 11/21/89
APVD [illegible] 11/22/89

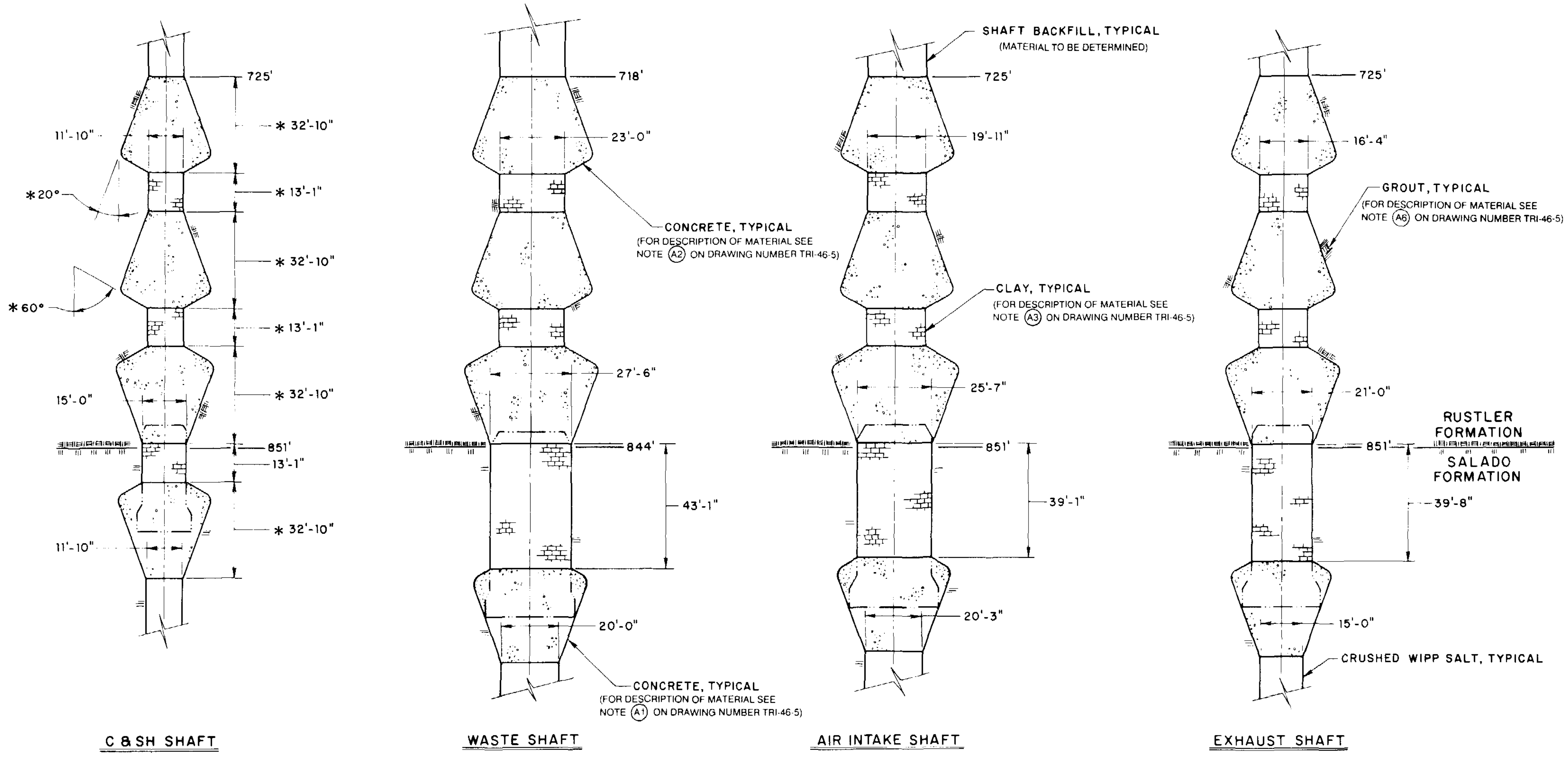
Sandia National Laboratories

TITLE SHAFT SEALS
WATER BEARING ZONE
PLAN AND SECTION

SIZE D
DWG NUMBER TRI-46-2
SCALE 1"=20'
SHEET 2 OF 5

Fig. 4. Shaft Seals Water Bearing Zone Plan and Section

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

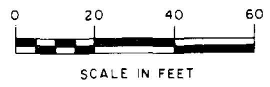


NOTES

1. DEPTH MEASUREMENTS INDICATE NUMBER OF FEET BELOW THE SURFACE, WHERE THE SURFACE EQUALS 0'-0". THE SURFACE ELEVATION THAT IS USED AS THE REFERENCE IS 3,409'-0" (USGS 1927 NORTH AMERICAN DATUM).
2. ALL STRATIGRAPHIC FEATURES ARE REPRESENTED ACCORDING TO DATA COMPILED FROM U.S. DEPARTMENT OF ENERGY, OCTOBER 1986, <u>WIPP DESIGN VALIDATION FINAL REPORT</u>, DOE-WIPP-86-010, BECHTEL NATIONAL INC., SAN FRANCISCO, CA.
3. THE UPPER SHAFT SEAL SYSTEM IS TO BE CONSTRUCTED AT A DEPTH WHERE THE BOTTOM TWO COMPONENTS (I.E., CLAY AND CONCRETE) RESIDE BELOW THE RUSTLER-SALADO CONTACT.
4. ALL SHAFT DRAWINGS REPRESENT EXCAVATED DIAMETERS (I.E., WITHOUT LINERS) FOR BOTH EXISTING AND PLANNED CONSTRUCTION. LINERS AND KEYS MUST BE REMOVED BEFORE SEAL EMPLACEMENTS.
5. EXISTING SHAFT KEYS ARE INDICATED BY DASHED LINES (·· — ··). THE KEYS ARE REPRESENTED ACCORDING TO INFORMATION OBTAINED FROM THE FOLLOWING DRAWING SETS:
    - A. WASTE SHAFT. US DOE/WIPP DRAWING 31-R-013-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 31-R-002-OID (WESTINGHOUSE, CARLSBAD, NM).
    - B. AIR INTAKE SHAFT. US DOE/WIPP DRAWING 33-R-001-34A (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 33-R-029-34A (BECHTEL, SAN FRANCISCO, CA).
    - C. EXHAUST SHAFT. US DOE/WIPP DRAWING 35-R-001-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 35-R-002-OID (BECHTEL, SAN FRANCISCO, CA).
    - D. *EXPLORATORY SHAFT. US DOE/WIPP DRAWING 37-R-010 (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 37-R-012 (BECHTEL, SAN FRANCISCO, CA).

*EXPLORATORY SHAFT HAS SINCE BEEN CHANGED TO CONSTRUCTION & SALT HANDLING SHAFT.

*** NOTE:**
THESE DIMENSIONS AND ANGLES ARE TYPICAL FOR ALL SHAFT CONFIGURATIONS.



SNL APPROVALS		
ORG	DATE	APPROVALS
63.4	..-89	Thomas E.
6314	11-22/89	
6346	11-28-89	
6346	11/29/89	

NEXT ASSEMBLY
APPLICATION

DR W. DUMAS / C. NORTHROP
CHK D.L. PULLIAM 11/21/89
ENG R. JONES 11/21/89
APVD 11/22/89

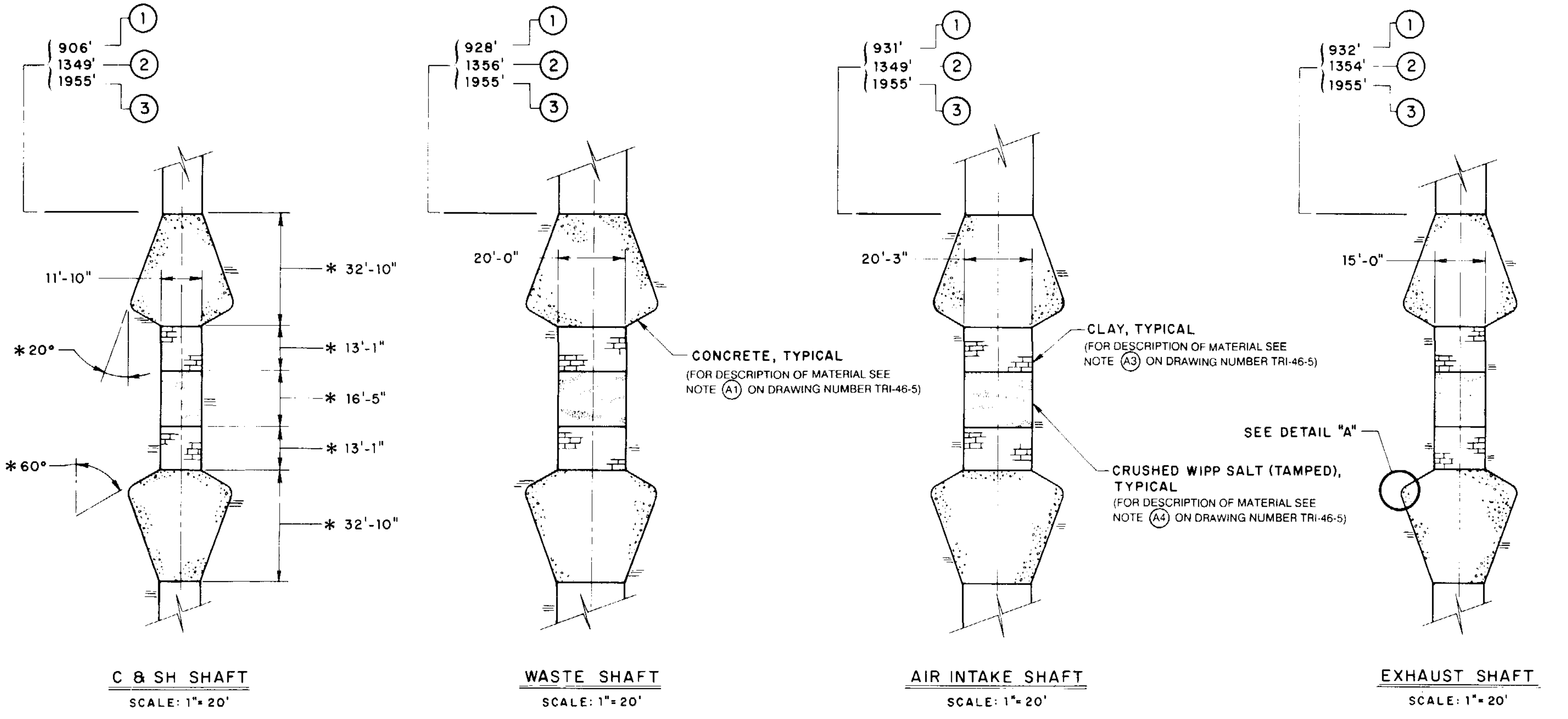
Sandia National Laboratories

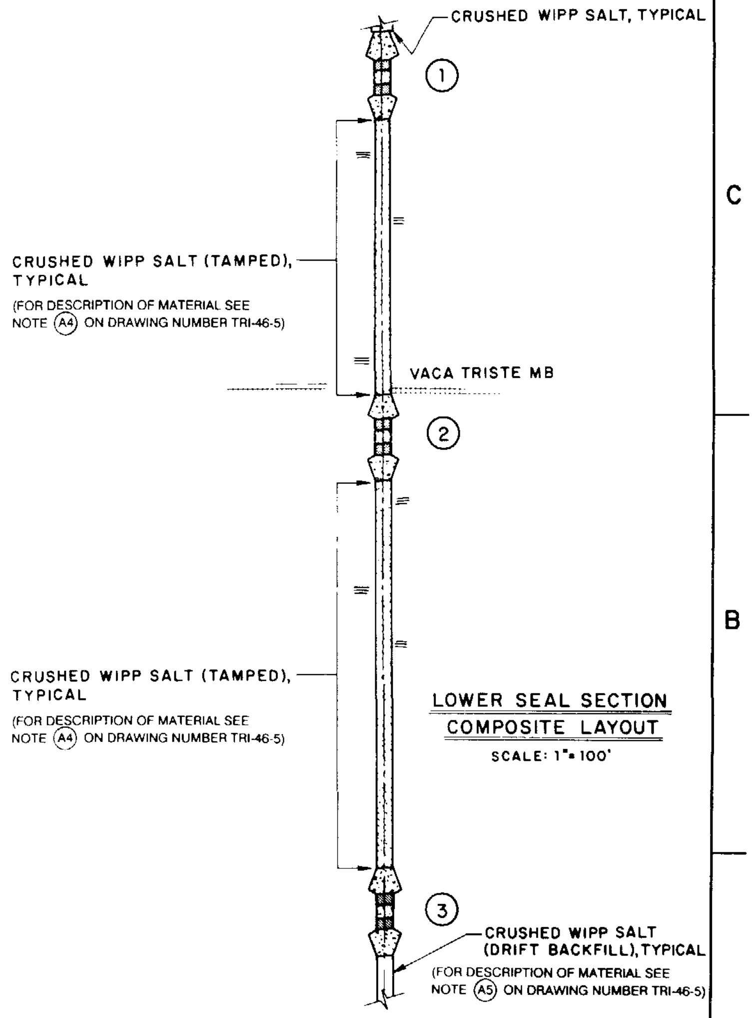
TITLE
SHAFT SEALS
UPPER SEAL SECTION

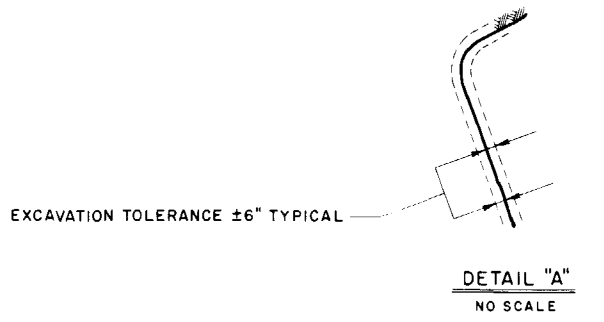
SIZE D
DWG NUMBER TRI-46-2
SCALE 1" = 20'
SHEET 3 OF 5

Fig. 5. Shaft Seals Upper Seal Section

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED







* NOTE:
THESE DIMENSIONS AND ANGLES ARE TYPICAL FOR ALL SHAFT CONFIGURATIONS.

NOTES

1. DEPTH MEASUREMENTS INDICATE NUMBER OF FEET BELOW THE SURFACE, WHERE THE SURFACE EQUALS 0'-0". THE SURFACE ELEVATION THAT IS USED AS THE REFERENCE IS 3,409'-0" (USGS 1927 NORTH AMERICAN DATUM).
2. ALL STRATIGRAPHIC FEATURES ARE REPRESENTED ACCORDING TO DATA COMPILED FROM U.S. DEPARTMENT OF ENERGY, OCTOBER 1986, WIPP DESIGN VALIDATION FINAL REPORT, DOE-WIPP-86-010, BECHTEL NATIONAL INC., SAN FRANCISCO, CA.
3. THE TOP COMPONENTS OF THE LOWER SHAFT SEALS ARE TO BE CONSTRUCTED AT A DEPTH NO LESS THAN 9'-10" BELOW THE UPPER SHAFT SEAL SYSTEM.
4. THE MIDDLE COMPONENTS OF THE LOWER SHAFT SEALS ARE TO BE CONSTRUCTED JUST BELOW THE VACA TRISTE MARKER BED.
5. THE BOTTOM COMPONENTS OF THE LOWER SHAFT SEALS ARE TO BE CONSTRUCTED AT THE 1955'-0" LEVEL FOR ALL SHAFTS.
6. ALL SHAFT DRAWINGS REPRESENT EXCAVATED DIAMETERS FOR BOTH EXISTING AND PLANNED CONSTRUCTION. THIS PORTION OF THE SHAFT IS UNLINED.
7. SHAFT DIAMETERS ARE REPRESENTED ACCORDING TO INFORMATION OBTAINED FROM THE FOLLOWING DRAWING SETS:
   - A. WASTE SHAFT. US DOE/WIPP DRAWING 31-R-013-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 31-R-002-OID (WESTINGHOUSE, CARLSBAD, NM).
   - B. AIR INTAKE SHAFT. US DOE/WIPP DRAWING 33-R-001-34A (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 33-R-029-34A (BECHTEL, SAN FRANCISCO, CA).
   - C. EXHAUST SHAFT. US DOE/WIPP DRAWING 35-R-001-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 35-R-002-OID (BECHTEL, SAN FRANCISCO, CA).
   - D. *EXPLORATORY SHAFT. US DOE/WIPP DRAWING 37-R-010 (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 37-R-012 (BECHTEL, SAN FRANCISCO, CA).

*EXPLORATORY SHAFT HAS SINCE BEEN CHANGED TO CONSTRUCTION & SALT HANDLING SHAFT.

0 20 40 60
SCALE IN FEET

SNL APPROVALS		
ORG	DATE	APPROVALS
6314	...89	Thomas [illegible]
6314	11/22/89	[illegible]
6346	11-28-89	J H Jones
6346	11/28/89	[illegible]

NEXT ASSEMBLY
APPLICATION

DR W. DUMAS / C. NORTHROP
CHK D L PULLIAM 11/21/89
ENG R. JONES 11/21/89
APVD [illegible] 11/22/89

Sandia National Laboratories

TITLE
SHAFT SEALS
LOWER SEAL SECTION

SIZE D
DWG NUMBER TRI-46-2
SCALE NOTED
SHEET 4 OF 5

Fig. 6. Shaft Seals Lower Seal Section

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

C & SH SHAFT

SHAFT SEAL SUMMARY

SEAL SYSTEM	MATERIAL	MAXIMUM DIAMETER (ft.)	SEAL INTERVAL BELOW GROUND SURFACE (ft.)
CAP, COLLAR, BACKFILL, AND PLUG	TO BE SPECIFIED	11.8	0.0 - 629.0
WATER BEARING ZONE	CONCRETE (BCT1FF GROUT)	31.6	629.0 - 661.8
	CLAY BLOCKS	11.8	661.8 - 674.9
	CONCRETE (BCT1FF GROUT)	31.6	674.9 - 707.7
SHAFT BACKFILL	TO BE SPECIFIED	11.8	707.7 - 725.0
UPPER SHAFT	CONCRETE (BCT1FF GROUT)	31.6	725.0 - 757.8
	CLAY BLOCKS	11.8	757.8 - 770.9
	CONCRETE (BCT1FF GROUT)	31.6	770.9 - 803.7
	CLAY BLOCKS	11.8	803.7 - 816.8
	CONCRETE (BCT1FF GROUT)	34.7	816.8 - 849.6
	CLAY BLOCKS	15.0	849.6 - 862.7
	CONCRETE (BCT1F GROUT)	31.6	862.7 - 895.5
SHAFT BACKFILL	CRUSHED WIPP SALT	11.8	895.5 - 905.5
LOWER SHAFT	CONCRETE (BCT1F GROUT)	31.6	905.5 - 938.3
	CLAY BLOCKS	11.8	938.3 - 951.4
	CRUSHED WIPP SALT (TAMPED)	11.8	951.4 - 967.8
	CLAY BLOCKS	11.8	967.8 - 980.9
	CONCRETE (BCT1F GROUT)	31.6	980.9 - 1013.7
	CRUSHED WIPP SALT (TAMPED)	11.8	1013.7 - 1349.0
	CONCRETE (BCT1F GROUT)	31.6	1349.0 - 1381.8
	CLAY BLOCKS	11.8	1381.8 - 1395.2
	CRUSHED WIPP SALT (TAMPED)	11.8	1395.2 - 1411.6
	CLAY BLOCKS	11.8	1411.6 - 1424.7
	CONCRETE (BCT1F GROUT)	31.6	1424.7 - 1457.5
	CRUSHED WIPP SALT (TAMPED)	11.8	1457.5 - 1955.0
	CONCRETE (BCT1F GROUT)	31.6	1955.0 - 1987.8
	CLAY BLOCKS	11.8	1987.8 - 2000.9
	CRUSHED WIPP SALT (TAMPED)	11.8	2000.9 - 2017.3
	CLAY BLOCKS	11.8	2017.3 - 2030.5
	CONCRETE (BCT1F GROUT)	31.6	2030.5 - 2063.3
DRIFT BACKFILL	CRUSHED WIPP SALT	11.8	2063.3 - 2272.0

EXISTING SHAFT DATA

MAJOR FEATURES	LEVEL BELOW SURFACE (ft.)	ORIGINAL EXCAVATION DIAMETER (ft.)
SURFACE	0.0	N/A
BOTTOM OF COLLAR	—	11.8
TOP OF MAGENTA	592.0	11.8
BOTTOM OF MAGENTA	627.0	11.8
TOP OF CULEBRA	710.0	11.8
BOTTOM OF CULEBRA	739.0	11.8
TOP OF KEY	842.4	11.8
RUSTLER/SALADO CONTACT	851.0	15.0
BOTTOM OF KEY	880.0	18.2
TOP OF VACA TRISTE	1348.0	11.8
BOTTOM OF VACA TRISTE	1349.0	11.8
TOP OF STATION	2141.0	11.8
STATION	2162.0	N/A
TOP OF SUMP	2162.0	11.8
BOTTOM OF SUMP	2272.0	11.8

WASTE SHAFT

SHAFT SEAL SUMMARY

SEAL SYSTEM	MATERIAL	MAXIMUM DIAMETER (ft.)	SEAL INTERVAL BELOW GROUND SURFACE (ft.)
CAP, COLLAR, BACKFILL, AND PLUG	TO BE SPECIFIED	23.0	0.0 - 623.0
WATER BEARING ZONE	CONCRETE (BCT1FF GROUT)	42.7	623.0 - 655.8
	CLAY BLOCKS	23.0	655.8 - 668.9
	CONCRETE (BCT1FF GROUT)	42.7	668.9 - 701.7
SHAFT BACKFILL	TO BE SPECIFIED	23.0	701.7 - 718.0
UPPER SHAFT	CONCRETE (BCT1FF GROUT)	42.7	718.0 - 750.8
	CLAY BLOCKS	23.0	750.8 - 763.9
	CONCRETE (BCT1FF GROUT)	42.7	763.9 - 796.7
	CLAY BLOCKS	23.0	796.7 - 809.8
	CONCRETE (BCT1FF GROUT)	47.2	809.8 - 842.6
	CLAY BLOCKS	27.5	842.6 - 885.7
	CONCRETE (BCT1F GROUT)	39.7	885.7 - 918.5
SHAFT BACKFILL	CRUSHED WIPP SALT	20.0	918.5 - 927.7
LOWER SHAFT	CONCRETE (BCT1F GROUT)	39.7	927.7 - 960.5
	CLAY BLOCKS	20.0	960.5 - 973.6
	CRUSHED WIPP SALT (TAMPED)	20.0	973.6 - 990.0
	CLAY BLOCKS	20.0	990.0 - 1003.1
	CONCRETE (BCT1F GROUT)	39.7	1003.1 - 1035.9
	CRUSHED WIPP SALT (TAMPED)	20.0	1035.9 - 1356.0
	CONCRETE (BCT1F GROUT)	39.7	1356.0 - 1388.8
	CLAY BLOCKS	20.0	1388.8 - 1401.9
	CRUSHED WIPP SALT (TAMPED)	20.0	1401.9 - 1418.3
	CLAY BLOCKS	20.0	1418.3 - 1431.4
	CONCRETE (BCT1F GROUT)	39.7	1431.4 - 1464.2
	CRUSHED WIPP SALT (TAMPED)	20.0	1464.2 - 1955.0
	CONCRETE (BCT1F GROUT)	39.7	1955.0 - 1987.8
	CLAY BLOCKS	20.0	1987.8 - 2000.9
	CRUSHED WIPP SALT (TAMPED)	20.0	2000.9 - 2017.3
	CLAY BLOCKS	20.0	2017.3 - 2030.5
	CONCRETE (BCT1F GROUT)	39.7	2030.5 - 2063.3
DRIFT BACKFILL	CRUSHED WIPP SALT	23.0	2063.3 - 2286.0

EXISTING SHAFT DATA

MAJOR FEATURES	LEVEL BELOW SURFACE (ft.)	ORIGINAL EXCAVATION DIAMETER (ft.)
SURFACE	0.0	N/A
BOTTOM OF COLLAR	21.0	24.0
TOP OF MAGENTA	597.0	23.0
BOTTOM OF MAGENTA	620.0	23.0
TOP OF CULEBRA	705.0	23.0
BOTTOM OF CULEBRA	727.0	23.0
TOP OF KEY	839.0	23.0
RUSTLER/SALADO CONTACT	844.0	27.5
BOTTOM OF KEY	902.0	31.0
TOP OF VACA TRISTE	1349.0	20.0
BOTTOM OF VACA TRISTE	1356.0	20.0
TOP OF STATION	2147.0	23.0
STATION	2160.0	N/A
TOP OF SUMP	2160.0	23.0
BOTTOM OF SUMP	2286.0	23.0

AIR INTAKE SHAFT

SHAFT SEAL SUMMARY

SEAL SYSTEM	MATERIAL	MAXIMUM DIAMETER (ft.)	SEAL INTERVAL BELOW GROUND SURFACE (ft.)
CAP, COLLAR, BACKFILL, AND PLUG	TO BE SPECIFIED	19.9	0.0 - 629.0
WATER BEARING ZONE	CONCRETE (BCT1FF GROUT)	39.6	629.0 - 661.8
	CLAY BLOCKS	19.9	661.8 - 674.9
	CONCRETE (BCT1FF GROUT)	39.6	674.9 - 707.7
SHAFT BACKFILL	TO BE SPECIFIED	19.9	707.7 - 725.0
UPPER SHAFT	CONCRETE (BCT1FF GROUT)	39.6	725.0 - 757.8
	CLAY BLOCKS	19.9	757.8 - 770.9
	CONCRETE (BCT1FF GROUT)	39.6	770.9 - 803.7
	CLAY BLOCKS	19.9	803.7 - 816.8
	CONCRETE (BCT1FF GROUT)	45.3	816.8 - 849.6
	CLAY BLOCKS	25.6	849.6 - 888.8
	CONCRETE (BCT1F GROUT)	40.0	888.8 - 921.6
SHAFT BACKFILL	CRUSHED WIPP SALT	20.2	921.6 - 931.4
LOWER SHAFT	CONCRETE (BCT1F GROUT)	40.0	931.4 - 964.2
	CLAY BLOCKS	20.2	964.2 - 977.4
	CRUSHED WIPP SALT (TAMPED)	20.2	977.4 - 993.8
	CLAY BLOCKS	20.2	993.8 - 1006.9
	CONCRETE (BCT1F GROUT)	40.0	1006.9 - 1039.7
	CRUSHED WIPP SALT (TAMPED)	20.2	1039.7 - 1349.0
	CONCRETE (BCT1F GROUT)	40.0	1349.0 - 1381.8
	CLAY BLOCKS	20.2	1381.8 - 1395.2
	CRUSHED WIPP SALT (TAMPED)	20.2	1395.2 - 1411.6
	CLAY BLOCKS	20.2	1411.6 - 1424.7
	CONCRETE (BCT1F GROUT)	40.0	1424.7 - 1457.5
	CRUSHED WIPP SALT (TAMPED)	20.2	1457.5 - 1955.0
	CONCRETE (BCT1F GROUT)	40.0	1955.0 - 1987.8
	CLAY BLOCKS	20.2	1987.8 - 2000.9
	CRUSHED WIPP SALT (TAMPED)	20.2	2000.9 - 2017.3
	CLAY BLOCKS	20.2	2017.3 - 2030.5
	CONCRETE (BCT1F GROUT)	40.0	2030.5 - 2063.3
DRIFT BACKFILL	CRUSHED WIPP SALT	20.2	2063.3 - 2150.0

EXISTING SHAFT DATA

MAJOR FEATURES	LEVEL BELOW SURFACE (ft.)	ORIGINAL EXCAVATION DIAMETER (ft.)
SURFACE	0.0	N/A
BOTTOM OF COLLAR	16.0	19.9
TOP OF MAGENTA	592.0	19.9
BOTTOM OF MAGENTA	627.0	19.9
TOP OF CULEBRA	710.0	19.9
BOTTOM OF CULEBRA	739.0	19.9
TOP OF KEY	843.5	19.9
RUSTLER/SALADO CONTACT	851.0	25.6
BOTTOM OF KEY	906.5	31.2
TOP OF VACA TRISTE	1348.0	20.2
BOTTOM OF VACA TRISTE	1349.0	20.2
TOP OF STATION	2135.0	20.2
STATION	2150.0	N/A

EXHAUST SHAFT

SHAFT SEAL SUMMARY

SEAL SYSTEM	MATERIAL	MAXIMUM DIAMETER (ft.)	SEAL INTERVAL BELOW GROUND SURFACE (ft.)
CAP, COLLAR, BACKFILL, AND PLUG	TO BE SPECIFIED	16.3	0.0 - 631.0
WATER BEARING ZONE	CONCRETE (BCT1FF GROUT)	36.0	631.0 - 663.9
	CLAY BLOCKS	16.3	663.9 - 677.1
	CONCRETE (BCT1FF GROUT)	36.0	677.1 - 709.9
SHAFT BACKFILL	TO BE SPECIFIED	16.3	709.9 - 725.0
UPPER SHAFT	CONCRETE (BCT1FF GROUT)	36.0	725.0 - 757.8
	CLAY BLOCKS	16.3	757.8 - 770.9
	CONCRETE (BCT1FF GROUT)	36.0	770.9 - 803.7
	CLAY BLOCKS	16.3	803.7 - 816.8
	CONCRETE (BCT1FF GROUT)	40.7	816.8 - 849.6
	CLAY BLOCKS	21.0	849.6 - 889.3
	CONCRETE (BCT1F GROUT)	34.7	889.3 - 922.1
SHAFT BACKFILL	CRUSHED WIPP SALT	15.0	922.1 - 931.9
LOWER SHAFT	CONCRETE (BCT1F GROUT)	34.7	931.9 - 964.7
	CLAY BLOCKS	15.0	964.7 - 977.9
	CRUSHED WIPP SALT (TAMPED)	15.0	977.9 - 994.3
	CLAY BLOCKS	15.0	994.3 - 1007.4
	CONCRETE (BCT1F GROUT)	34.7	1007.4 - 1040.2
	CRUSHED WIPP SALT (TAMPED)	15.0	1040.2 - 1354.0
	CONCRETE (BCT1F GROUT)	34.7	1354.0 - 1386.8
	CLAY BLOCKS	15.0	1386.8 - 1399.9
	CRUSHED WIPP SALT (TAMPED)	15.0	1399.9 - 1416.3
	CLAY BLOCKS	15.0	1416.3 - 1429.4
	CONCRETE (BCT1F GROUT)	34.7	1429.4 - 1462.2
	CRUSHED WIPP SALT (TAMPED)	15.0	1462.2 - 1955.0
	CONCRETE (BCT1F GROUT)	34.7	1955.0 - 1987.8
	CLAY BLOCKS	15.0	1987.8 - 2000.9
	CRUSHED WIPP SALT (TAMPED)	15.0	2000.9 - 2017.3
	CLAY BLOCKS	15.0	2017.3 - 2030.5
	CONCRETE (BCT1F GROUT)	34.7	2030.5 - 2063.3
DRIFT BACKFILL	CRUSHED WIPP SALT	15.0	2063.3 - 2157.0

EXISTING SHAFT DATA

MAJOR FEATURES	LEVEL BELOW SURFACE (ft.)	ORIGINAL EXCAVATION DIAMETER (ft.)
SURFACE	0.0	N/A
BOTTOM OF COLLAR	10.0	15.7
TOP OF MAGENTA	603.0	16.3
BOTTOM OF MAGENTA	627.0	16.3
TOP OF CULEBRA	714.0	16.3
BOTTOM OF CULEBRA	736.0	16.3
TOP OF KEY	844.0	16.7
RUSTLER/SALADO CONTACT	851.0	21.0
BOTTOM OF KEY	907.0	26.0
TOP OF VACA TRISTE	1354.0	15.0
BOTTOM OF VACA TRISTE	1357.0	15.0
TOP OF STATION	2147.0	15.0
STATION	2157.0	N/A

NOTES

1. TABLES THAT PRESENT EXISTING SHAFT DATA ARE GENERATED ACCORDING TO INFORMATION OBTAINED FROM THE FOLLOWING DRAWING SETS:
   - A. WASTE SHAFT. US DOE/WIPP DRAWING 31-R-013-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 31-R-002-OID (WESTINGHOUSE, CARLSBAD, NM)
   - B. AIR INTAKE SHAFT. US DOE/WIPP DRAWING 33-R-001-34A (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 33-R-029-34A (BECHTEL, SAN FRANCISCO, CA)
   - C. EXHAUST SHAFT. US DOE/WIPP DRAWING 35-R-001-OID (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 35-R-002-OID (BECHTEL, SAN FRANCISCO, CA).
   - D *EXPLORATORY SHAFT. US DOE/WIPP DRAWING 37-R-010 (BECHTEL, SAN FRANCISCO, CA) AND US DOE/WIPP DRAWING 37-R-012 (BECHTEL, SAN FRANCISCO, CA).
2. ALL STRATIGRAPHIC FEATURES ARE REPRESENTED ACCORDING TO DATA COMPILED FROM U.S. DEPARTMENT OF ENERGY, OCTOBER 1986, WIPP DESIGN VALIDATION FINAL REPORT, DOE-WIPP-86-010, BECHTEL NATIONAL INC. SAN FRANCISCO, CA.

*EXPLORATORY SHAFT HAS SINCE BEEN CHANGED TO CONSTRUCTION & SALT HANDLING SHAFT

SNL APPROVALS		
ORG	DATE	APPROVALS
6311	/22/89	
6314	11/21/89	
6346	11-...	
6346	11/28/89	

NEXT ASSEMBLY

APPLICATION

DR C NORTHROP

CHK D L PULLIAM 11/21/89

ENG R JONES 11/21/89

APVD 11/22/89

Sandia National Laboratories

TITLE
SHAFT SEALS
RELEVANT INFORMATION

SIZE D

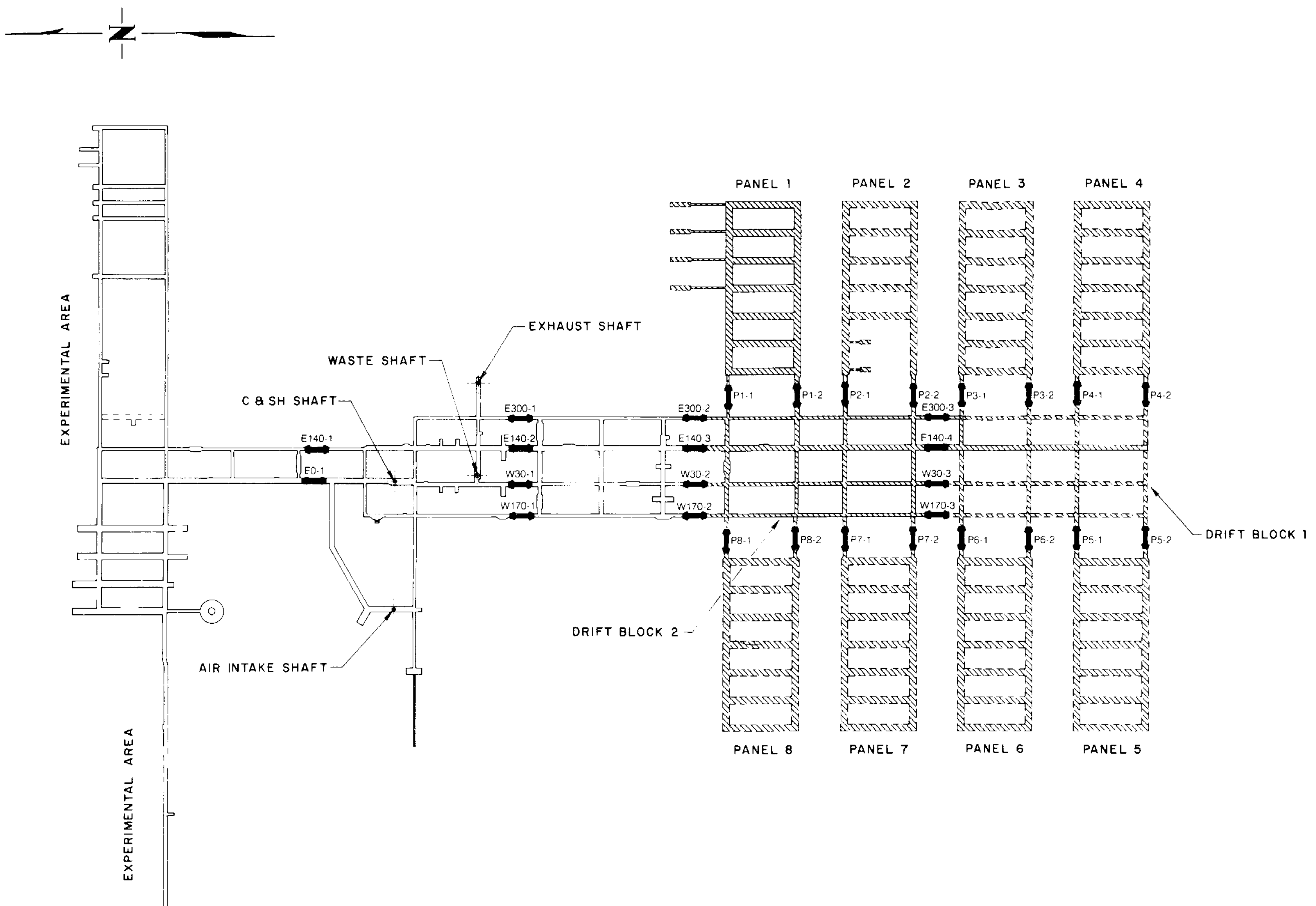
DWG NUMBER TRI-46-2

SCALE

SHEET 5 OF 5

Fig. 7. Shaft Seals Relevant Information

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



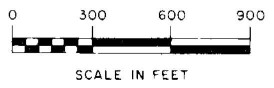
DRIFT DIMENSIONS AT PROPOSED SEAL LOCATIONS

	SEAL NUMBER	NOMINAL WIDTH (ft)	NOMINAL HEIGHT (ft)	*SECTION TYPE
DRIFT SEALS	E300-1	14	12	C-C
	E300-2	14	12	C-C
	E300-3	14	12	C-C
	E140-1	14	18	B-B
	E140 2	25	12	A-A
	E140-3	25	12	A-A
	E140-4	25	12	A-A
	E0-1	25	12	A-A
	W30-1	20	12	D-D
	W30-2	14	12	C-C
	W30-3	14	12	C-C
	W170-1	14	12	C C
	W170-2	14	12	C-C
	W170-3	14	12	C C
PANEL SEALS	P1-1	14	12	C-C
	P1-2	20	12	D-D
	P2-1	14	12	C-C
	P2-2	20	12	D-D
	P3-1	14	12	C C
	P3-2	20	12	D D
	P4-1	14	12	C-C
	P4-2	20	12	D-D
	P5-1	14	12	C-C
	P5-2	20	12	D-D
	P6-1	14	12	C-C
	P6-2	20	12	D D
	P7-1	14	12	C C
	P7-2	20	12	D D
	P8-1	14	12	C-C
	P8-2	20	12	D-D

*REFER TO TRI-46-3, 2 OF 2 FOR SECTION DETAILS

LEGEND

═	EXISTING EXCAVATION
┄	PLANNED EXCAVATION
●━●	DRIFT SEALS
▨	WASTE DISPOSAL AREAS



NOTES

1. DRIFT BLOCK 1 CONSISTS OF THE INTERSECTING DRIFTS BOUNDED BY THE FOLLOWING SEALS. P3-1, P3-2, P4-1, P4-2, P5-2, P5-1, P6-2, P6-1, W170-3, W30-3, E140-4, AND E300-3.

2. DRIFT BLOCK 2 CONSISTS OF THE INTERSECTING DRIFTS BOUNDED BY THE FOLLOWING SEALS: P1-1, P1-2, P2-1, P2-2, P7-2, P7-1, P8-2, P8-1, W170-2, W30-2, E140-3, AND E300-2.

3. IN EACH WASTE DISPOSAL AREA, WASTE EMPLACEMENT, BACKFILLING, AND SEALING WILL BE COMPLETED BEFORE PROCEEDING WITH THOSE OPERATIONS IN THE NEXT AREA. THE WASTE DISPOSAL AREAS ARE PANELS 1 THROUGH 8, DRIFT BLOCK 1, AND DRIFT BLOCK 2. PANEL 1 WILL BE THE FIRST AREA TO BE COMPLETED, FOLLOWED BY PANEL 2, AND CONTINUING IN NUMERICAL SEQUENCE THROUGH PANEL 8. AFTER THE EIGHT PANELS ARE FINISHED, THE DRIFT BLOCKS WILL BE COMPLETED; FIRST BLOCK 1 FOLLOWED BY BLOCK 2.

   THE SEALS WILL BE CONSTRUCTED BETWEEN EACH WASTE DISPOSAL AREA AND OPEN ACCESS DRIFTS. FOR EXAMPLE, SEALS P1-1 AND P1-2 WILL BE BUILT FOLLOWING WASTE EMPLACEMENT AND BACKFILLING IN PANEL 1, AND SEALS E300-3, E140-4, W30-3, AND W170-3 WILL BE BUILT FOLLOWING WASTE EMPLACEMENT AND BACKFILLING IN DRIFT BLOCK 1.

SNL APPROVALS		
ORG	DATE	APPROVALS
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
6346	11-28-89	J M Jones
6346	11/28/89	Joe R Tillerson

NEXT ASSEMBLY

APPLICATION

DR W. DUMAS

CHK D L PULLIAM [illegible] 89

ENG R JONES 11 21 89

APVD [illegible] 11/22/89

Sandia National Laboratories

TITLE
DRIFT AND PANEL SEALS
GENERAL ARRANGEMENT

SIZE D

DWG NUMBER TRI-46-3

SCALE 1"=300'

SHEET 1 OF 2

Fig. 8. Drift and Panel Seals General Arrangement

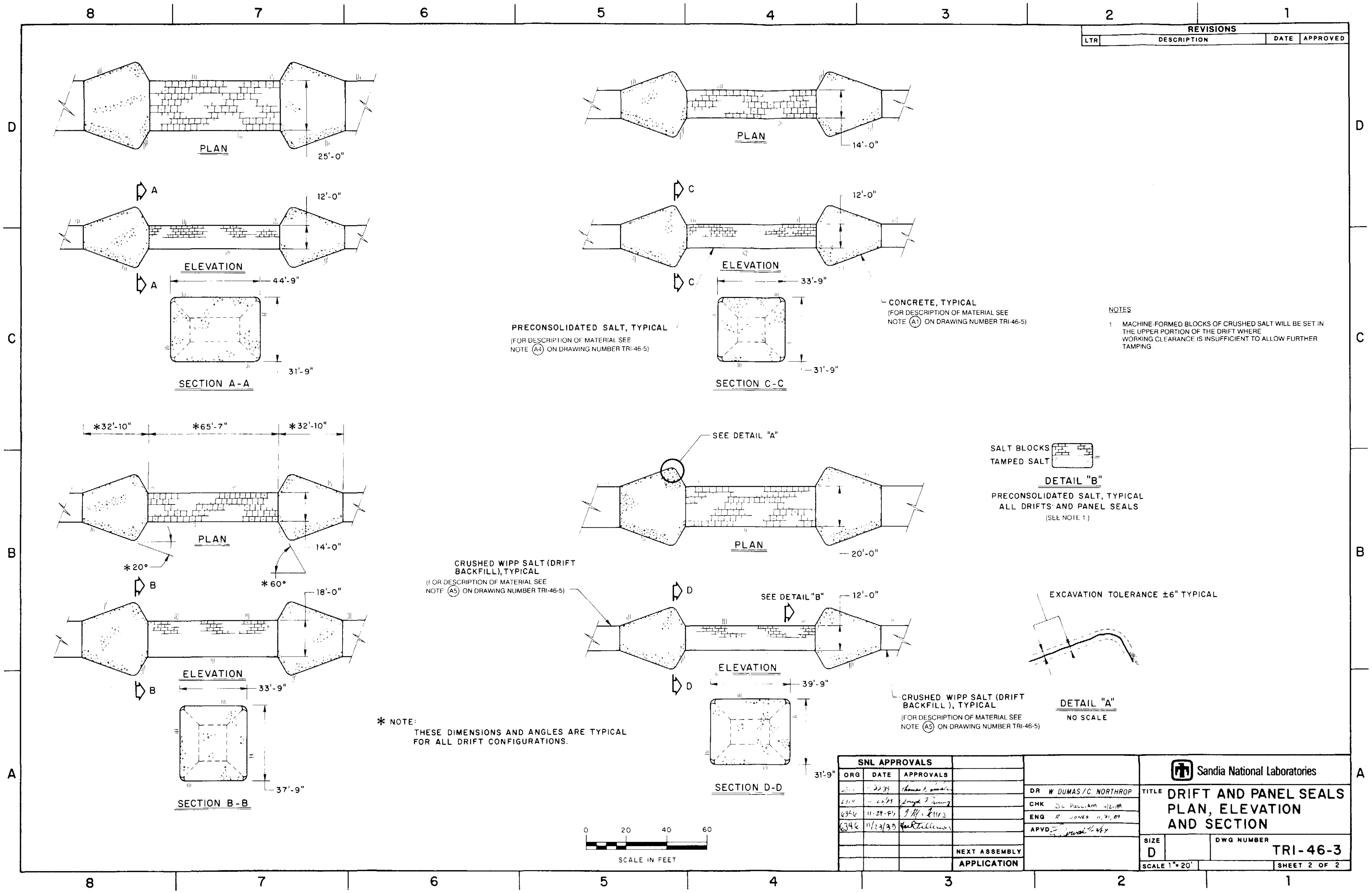
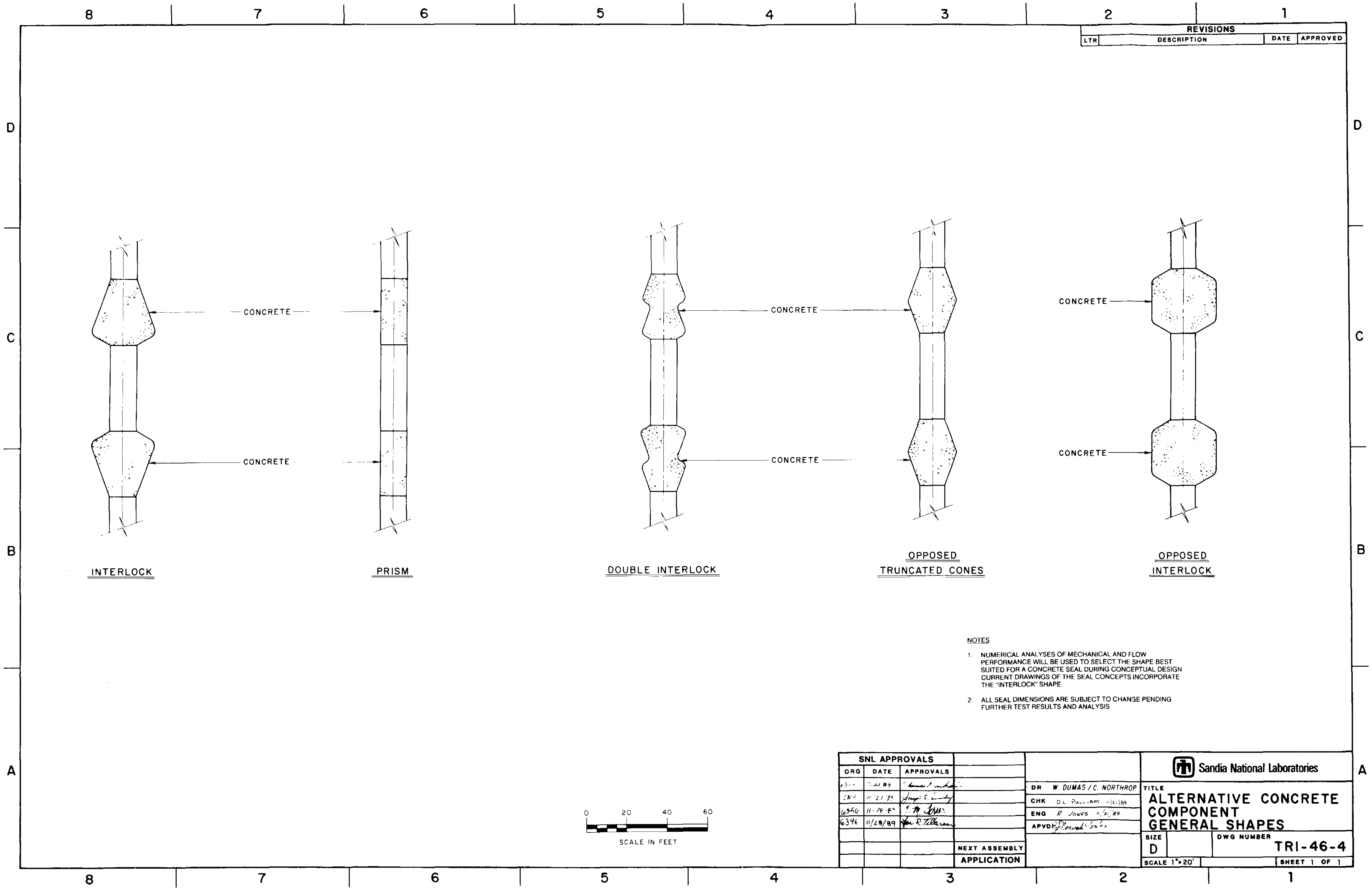


Fig. 9. Drift and Panel Seals Plan, Elevation and Section



NOTES

1. NUMERICAL ANALYSES OF MECHANICAL AND FLOW PERFORMANCE WILL BE USED TO SELECT THE SHAPE BEST SUITED FOR A CONCRETE SEAL DURING CONCEPTUAL DESIGN. CURRENT DRAWINGS OF THE SEAL CONCEPTS INCORPORATE THE "INTERLOCK" SHAPE.

2. ALL SEAL DIMENSIONS ARE SUBJECT TO CHANGE PENDING FURTHER TEST RESULTS AND ANALYSIS.

SNL APPROVALS		
ORG	DATE	APPROVALS
63[illegible]	11-22-89	[illegible]
63[illegible]	11-22-89	[illegible]
6346	11-28-89	J. M. Jones
6346	11/28/89	Joe R. Tillerson

NEXT ASSEMBLY
APPLICATION

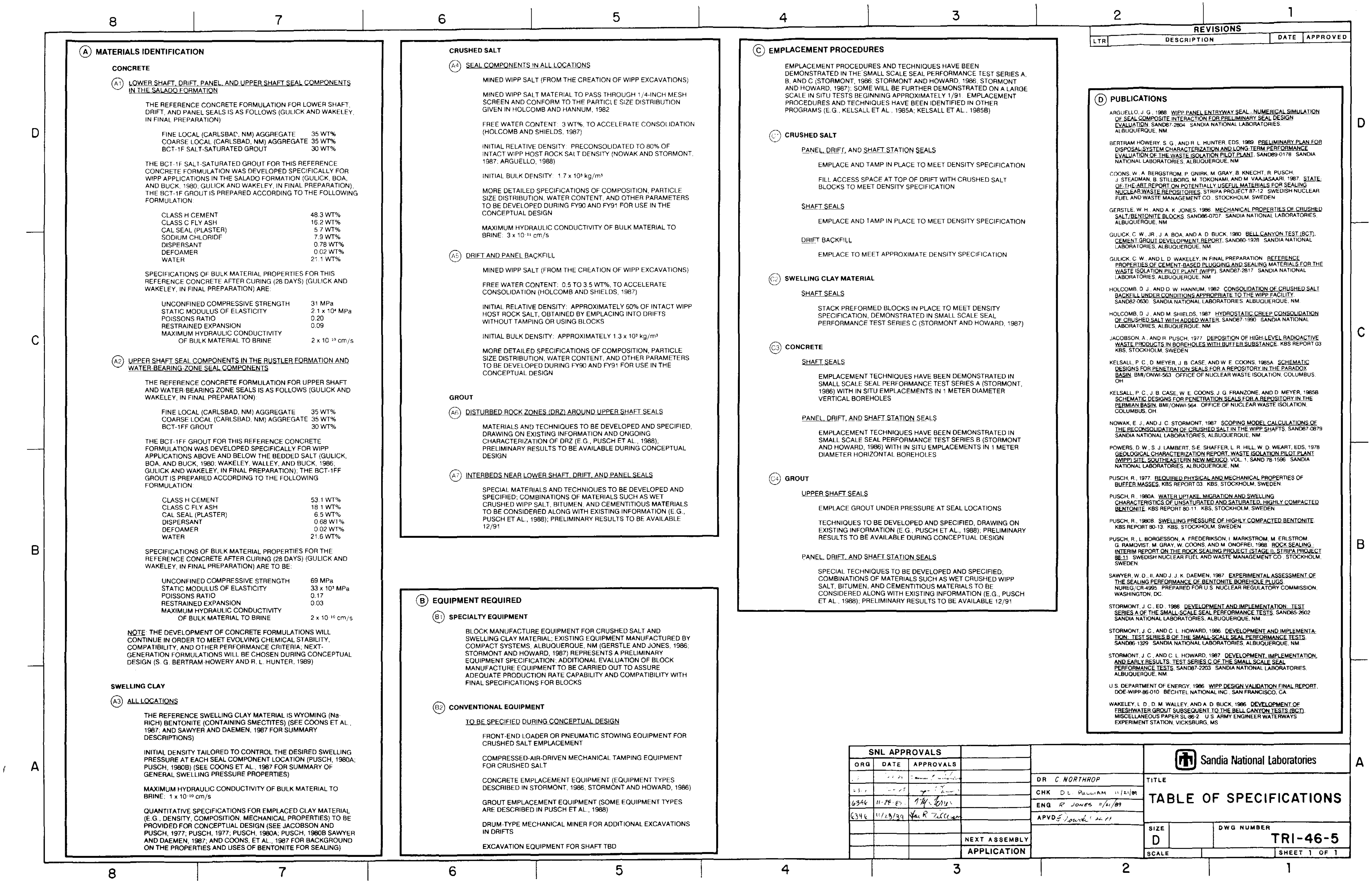
DR W. DUMAS / C. NORTHROP
CHK D L PULLIAM 11/21/89
ENG R JONES 11/21/89
APVD E J Nowak 11/22/89

Sandia National Laboratories

TITLE
ALTERNATIVE CONCRETE
COMPONENT
GENERAL SHAPES

SIZE D
DWG NUMBER TRI-46-4
SCALE 1"=20'
SHEET 1 OF 1

Fig. 10. Alternative Concrete Component General Shapes



REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

Ⓐ MATERIALS IDENTIFICATION

CONCRETE

(A1) LOWER SHAFT, DRIFT, PANEL, AND UPPER SHAFT SEAL COMPONENTS IN THE SALADO FORMATION

THE REFERENCE CONCRETE FORMULATION FOR LOWER SHAFT, DRIFT, AND PANEL SEALS IS AS FOLLOWS (GULICK AND WAKELEY, IN FINAL PREPARATION):

FINE LOCAL (CARLSBAD, NM) AGGREGATE	35 WT%
COARSE LOCAL (CARLSBAD, NM) AGGREGATE	35 WT%
BCT-1F SALT-SATURATED GROUT	30 WT%

THE BCT-1F SALT-SATURATED GROUT FOR THIS REFERENCE CONCRETE FORMULATION WAS DEVELOPED SPECIFICALLY FOR WIPP APPLICATIONS IN THE SALADO FORMATION (GULICK, BOA, AND BUCK, 1980; GULICK AND WAKELEY, IN FINAL PREPARATION), THE BCT-1F GROUT IS PREPARED ACCORDING TO THE FOLLOWING FORMULATION:

CLASS H CEMENT	48.3 WT%
CLASS C FLY ASH	16.2 WT%
CAL SEAL (PLASTER)	5.7 WT%
SODIUM CHLORIDE	7.9 WT%
DISPERSANT	0.78 WT%
DEFOAMER	0.02 WT%
WATER	21.1 WT%

SPECIFICATIONS OF BULK MATERIAL PROPERTIES FOR THIS REFERENCE CONCRETE AFTER CURING (28 DAYS) (GULICK AND WAKELEY, IN FINAL PREPARATION) ARE:

UNCONFINED COMPRESSIVE STRENGTH	31 MPa
STATIC MODULUS OF ELASTICITY	2.1×10^4 MPa
POISSONS RATIO	0.20
RESTRAINED EXPANSION	0.09
MAXIMUM HYDRAULIC CONDUCTIVITY OF BULK MATERIAL TO BRINE	2×10^{-10} cm/s

(A2) UPPER SHAFT SEAL COMPONENTS IN THE RUSTLER FORMATION AND WATER-BEARING-ZONE SEAL COMPONENTS

THE REFERENCE CONCRETE FORMULATION FOR UPPER SHAFT AND WATER-BEARING ZONE SEALS IS AS FOLLOWS (GULICK AND WAKELEY, IN FINAL PREPARATION):

FINE LOCAL (CARLSBAD, NM) AGGREGATE	35 WT%
COARSE LOCAL (CARLSBAD, NM) AGGREGATE	35 WT%
BCT-1FF GROUT	30 WT%

THE BCT-1FF GROUT FOR THIS REFERENCE CONCRETE FORMULATION WAS DEVELOPED SPECIFICALLY FOR WIPP APPLICATIONS ABOVE AND BELOW THE BEDDED SALT (GULICK, BOA, AND BUCK, 1980; WAKELEY, WALLEY, AND BUCK, 1986; GULICK AND WAKELEY, IN FINAL PREPARATION); THE BCT-1FF GROUT IS PREPARED ACCORDING TO THE FOLLOWING FORMULATION:

CLASS H CEMENT	53.1 WT%
CLASS C FLY ASH	18.1 WT%
CAL SEAL (PLASTER)	6.5 WT%
DISPERSANT	0.68 WT%
DEFOAMER	0.02 WT%
WATER	21.6 WT%

SPECIFICATIONS OF BULK MATERIAL PROPERTIES FOR THE REFERENCE CONCRETE AFTER CURING (28 DAYS) (GULICK AND WAKELEY, IN FINAL PREPARATION) ARE TO BE:

UNCONFINED COMPRESSIVE STRENGTH	69 MPa
STATIC MODULUS OF ELASTICITY	33×10^3 MPa
POISSONS RATIO	0.17
RESTRAINED EXPANSION	0.03
MAXIMUM HYDRAULIC CONDUCTIVITY OF BULK MATERIAL TO BRINE	2×10^{-10} cm/s

NOTE: THE DEVELOPMENT OF CONCRETE FORMULATIONS WILL CONTINUE IN ORDER TO MEET EVOLVING CHEMICAL STABILITY, COMPATIBILITY, AND OTHER PERFORMANCE CRITERIA; NEXT-GENERATION FORMULATIONS WILL BE CHOSEN DURING CONCEPTUAL DESIGN (S. G. BERTRAM-HOWERY AND R. L. HUNTER, 1989)

SWELLING CLAY

(A3) ALL LOCATIONS

THE REFERENCE SWELLING CLAY MATERIAL IS WYOMING (Na-RICH) BENTONITE (CONTAINING SMECTITES) (SEE COONS ET AL., 1987; AND SAWYER AND DAEMEN, 1987 FOR SUMMARY DESCRIPTIONS)

INITIAL DENSITY TAILORED TO CONTROL THE DESIRED SWELLING PRESSURE AT EACH SEAL COMPONENT LOCATION (PUSCH, 1980A; PUSCH, 1980B) (SEE COONS ET AL., 1987 FOR SUMMARY OF GENERAL SWELLING PRESSURE PROPERTIES)

MAXIMUM HYDRAULIC CONDUCTIVITY OF BULK MATERIAL TO BRINE: 1×10^{-10} cm/s

QUANTITATIVE SPECIFICATIONS FOR EMPLACED CLAY MATERIAL (E.G., DENSITY, COMPOSITION, MECHANICAL PROPERTIES) TO BE PROVIDED FOR CONCEPTUAL DESIGN (SEE JACOBSON AND PUSCH, 1977; PUSCH, 1977; PUSCH, 1980A; PUSCH, 1980B SAWYER AND DAEMEN, 1987; AND COONS, ET AL., 1987 FOR BACKGROUND ON THE PROPERTIES AND USES OF BENTONITE FOR SEALING)

CRUSHED SALT

(A4) SEAL COMPONENTS IN ALL LOCATIONS

MINED WIPP SALT (FROM THE CREATION OF WIPP EXCAVATIONS)

MINED WIPP SALT MATERIAL TO PASS THROUGH 1/4-INCH MESH SCREEN AND CONFORM TO THE PARTICLE SIZE DISTRIBUTION GIVEN IN HOLCOMB AND HANNUM, 1982

FREE WATER CONTENT: 3 WT%, TO ACCELERATE CONSOLIDATION (HOLCOMB AND SHIELDS, 1987)

INITIAL RELATIVE DENSITY: PRECONSOLIDATED TO 80% OF INTACT WIPP HOST ROCK SALT DENSITY (NOWAK AND STORMONT, 1987; ARGUELLO, 1988)

INITIAL BULK DENSITY: 1.7×10^3 kg/m^3

MORE DETAILED SPECIFICATIONS OF COMPOSITION, PARTICLE SIZE DISTRIBUTION, WATER CONTENT, AND OTHER PARAMETERS TO BE DEVELOPED DURING FY90 AND FY91 FOR USE IN THE CONCEPTUAL DESIGN

MAXIMUM HYDRAULIC CONDUCTIVITY OF BULK MATERIAL TO BRINE: 3×10^{-11} cm/s

(A5) DRIFT AND PANEL BACKFILL

MINED WIPP SALT (FROM THE CREATION OF WIPP EXCAVATIONS)

FREE WATER CONTENT: 0.5 TO 3.5 WT%, TO ACCELERATE CONSOLIDATION (HOLCOMB AND SHIELDS, 1987)

INITIAL RELATIVE DENSITY: APPROXIMATELY 60% OF INTACT WIPP HOST ROCK SALT, OBTAINED BY EMPLACING INTO DRIFTS WITHOUT TAMPING OR USING BLOCKS

INITIAL BULK DENSITY: APPROXIMATELY 1.3×10^3 kg/m^3

MORE DETAILED SPECIFICATIONS OF COMPOSITION, PARTICLE SIZE DISTRIBUTION, WATER CONTENT, AND OTHER PARAMETERS TO BE DEVELOPED DURING FY90 AND FY91 FOR USE IN THE CONCEPTUAL DESIGN

GROUT

(A6) DISTURBED ROCK ZONES (DRZ) AROUND UPPER SHAFT SEALS

MATERIALS AND TECHNIQUES TO BE DEVELOPED AND SPECIFIED, DRAWING ON EXISTING INFORMATION AND ONGOING CHARACTERIZATION OF DRZ (E.G., PUSCH ET AL., 1988); PRELIMINARY RESULTS TO BE AVAILABLE DURING CONCEPTUAL DESIGN

(A7) INTERBEDS NEAR LOWER SHAFT, DRIFT, AND PANEL SEALS

SPECIAL MATERIALS AND TECHNIQUES TO BE DEVELOPED AND SPECIFIED; COMBINATIONS OF MATERIALS SUCH AS WET CRUSHED WIPP SALT, BITUMEN, AND CEMENTITIOUS MATERIALS TO BE CONSIDERED ALONG WITH EXISTING INFORMATION (E.G., PUSCH ET AL., 1988); PRELIMINARY RESULTS TO BE AVAILABLE 12/91

Ⓑ EQUIPMENT REQUIRED

(B1) SPECIALTY EQUIPMENT

BLOCK MANUFACTURE EQUIPMENT FOR CRUSHED SALT AND SWELLING CLAY MATERIAL; EXISTING EQUIPMENT MANUFACTURED BY COMPACT SYSTEMS, ALBUQUERQUE, NM (GERSTLE AND JONES, 1986; STORMONT AND HOWARD, 1987) REPRESENTS A PRELIMINARY EQUIPMENT SPECIFICATION; ADDITIONAL EVALUATION OF BLOCK MANUFACTURE EQUIPMENT TO BE CARRIED OUT TO ASSURE ADEQUATE PRODUCTION RATE CAPABILITY AND COMPATIBILITY WITH FINAL SPECIFICATIONS FOR BLOCKS

(B2) CONVENTIONAL EQUIPMENT

TO BE SPECIFIED DURING CONCEPTUAL DESIGN

FRONT-END LOADER OR PNEUMATIC STOWING EQUIPMENT FOR CRUSHED SALT EMPLACEMENT

COMPRESSED-AIR-DRIVEN MECHANICAL TAMPING EQUIPMENT FOR CRUSHED SALT

CONCRETE EMPLACEMENT EQUIPMENT (EQUIPMENT TYPES DESCRIBED IN STORMONT, 1986; STORMONT AND HOWARD, 1986)

GROUT EMPLACEMENT EQUIPMENT (SOME EQUIPMENT TYPES ARE DESCRIBED IN PUSCH ET AL., 1988)

DRUM-TYPE MECHANICAL MINER FOR ADDITIONAL EXCAVATIONS IN DRIFTS

EXCAVATION EQUIPMENT FOR SHAFT TBD

Ⓒ EMPLACEMENT PROCEDURES

EMPLACEMENT PROCEDURES AND TECHNIQUES HAVE BEEN DEMONSTRATED IN THE SMALL SCALE SEAL PERFORMANCE TEST SERIES A, B, AND C (STORMONT, 1986; STORMONT AND HOWARD, 1986, STORMONT AND HOWARD, 1987); SOME WILL BE FURTHER DEMONSTRATED ON A LARGE SCALE IN SITU TESTS BEGINNING APPROXIMATELY 1/91. EMPLACEMENT PROCEDURES AND TECHNIQUES HAVE BEEN IDENTIFIED IN OTHER PROGRAMS (E.G., KELSALL ET AL., 1985A; KELSALL ET AL., 1985B)

(C1) CRUSHED SALT

PANEL, DRIFT, AND SHAFT STATION SEALS

EMPLACE AND TAMP IN PLACE TO MEET DENSITY SPECIFICATION

FILL ACCESS SPACE AT TOP OF DRIFT WITH CRUSHED SALT BLOCKS TO MEET DENSITY SPECIFICATION

SHAFT SEALS

EMPLACE AND TAMP IN PLACE TO MEET DENSITY SPECIFICATION

DRIFT BACKFILL

EMPLACE TO MEET APPROXIMATE DENSITY SPECIFICATION

(C2) SWELLING CLAY MATERIAL

SHAFT SEALS

STACK PREFORMED BLOCKS IN PLACE TO MEET DENSITY SPECIFICATION, DEMONSTRATED IN SMALL SCALE SEAL PERFORMANCE TEST SERIES C (STORMONT AND HOWARD, 1987)

(C3) CONCRETE

SHAFT SEALS

EMPLACEMENT TECHNIQUES HAVE BEEN DEMONSTRATED IN SMALL SCALE SEAL PERFORMANCE TEST SERIES A (STORMONT, 1986) WITH IN SITU EMPLACEMENTS IN 1 METER DIAMETER VERTICAL BOREHOLES

PANEL, DRIFT, AND SHAFT STATION SEALS

EMPLACEMENT TECHNIQUES HAVE BEEN DEMONSTRATED IN SMALL SCALE SEAL PERFORMANCE TEST SERIES B (STORMONT AND HOWARD, 1986) WITH IN SITU EMPLACEMENTS IN 1 METER DIAMETER HORIZONTAL BOREHOLES

(C4) GROUT

UPPER SHAFT SEALS

EMPLACE GROUT UNDER PRESSURE AT SEAL LOCATIONS

TECHNIQUES TO BE DEVELOPED AND SPECIFIED, DRAWING ON EXISTING INFORMATION (E.G., PUSCH ET AL., 1988); PRELIMINARY RESULTS TO BE AVAILABLE DURING CONCEPTUAL DESIGN

PANEL, DRIFT, AND SHAFT STATION SEALS

SPECIAL TECHNIQUES TO BE DEVELOPED AND SPECIFIED; COMBINATIONS OF MATERIALS SUCH AS WET CRUSHED WIPP SALT, BITUMEN, AND CEMENTITIOUS MATERIALS TO BE CONSIDERED ALONG WITH EXISTING INFORMATION (E.G., PUSCH ET AL., 1988); PRELIMINARY RESULTS TO BE AVAILABLE 12/91

Ⓓ PUBLICATIONS

ARGUELLO, J. G., 1988. WIPP PANEL ENTRYWAY SEAL - NUMERICAL SIMULATION OF SEAL COMPOSITE INTERACTION FOR PRELIMINARY SEAL DESIGN EVALUATION, SAND87-2804. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

BERTRAM HOWERY, S. G., AND R. L. HUNTER, EDS, 1989. PRELIMINARY PLAN FOR DISPOSAL-SYSTEM CHARACTERIZATION AND LONG-TERM PERFORMANCE EVALUATION OF THE WASTE ISOLATION PILOT PLANT, SAND89-0178. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

COONS, W., A. BERGSTROM, P. GNIRK, M. GRAY, B. KNECHT, R. PUSCH, J. STEADMAN, B. STILLBORG, M. TOKONAMI, AND M. VAAJASAARI, 1987. STATE-OF-THE-ART REPORT ON POTENTIALLY USEFUL MATERIALS FOR SEALING NUCLEAR WASTE REPOSITORIES. STRIPA PROJECT 87-12. SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO., STOCKHOLM, SWEDEN

GERSTLE, W. H., AND A. K. JONES, 1986. MECHANICAL PROPERTIES OF CRUSHED SALT/BENTONITE BLOCKS, SAND86-0707. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

GULICK, C. W., JR., J. A. BOA, AND A. D. BUCK, 1980. BELL CANYON TEST (BCT), CEMENT GROUT DEVELOPMENT REPORT, SAND80-1928. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

GULICK, C. W., AND L. D. WAKELEY, IN FINAL PREPARATION. REFERENCE PROPERTIES OF CEMENT-BASED PLUGGING AND SEALING MATERIALS FOR THE WASTE ISOLATION PILOT PLANT (WIPP), SAND87-2817. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

HOLCOMB, D. J., AND D. W. HANNUM, 1982. CONSOLIDATION OF CRUSHED SALT BACKFILL UNDER CONDITIONS APPROPRIATE TO THE WIPP FACILITY, SAND82-0630. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

HOLCOMB, D. J., AND M. SHIELDS, 1987. HYDROSTATIC CREEP CONSOLIDATION OF CRUSHED SALT WITH ADDED WATER, SAND87-1990. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

JACOBSON, A., AND R. PUSCH, 1977. DEPOSITION OF HIGH-LEVEL RADIOACTIVE WASTE PRODUCTS IN BOREHOLES WITH BUFFER SUBSTANCE, KBS REPORT 03. KBS, STOCKHOLM, SWEDEN

KELSALL, P. C., D. MEYER, J. B. CASE, AND W. E. COONS, 1985A. SCHEMATIC DESIGNS FOR PENETRATION SEALS FOR A REPOSITORY IN THE PARADOX BASIN, BMI/ONWI-563. OFFICE OF NUCLEAR WASTE ISOLATION, COLUMBUS, OH

KELSALL, P. C., J. B. CASE, W. E. COONS, J. G. FRANZONE, AND D. MEYER, 1985B. SCHEMATIC DESIGNS FOR PENETRATION SEALS FOR A REPOSITORY IN THE PERMIAN BASIN, BMI/ONWI-564. OFFICE OF NUCLEAR WASTE ISOLATION, COLUMBUS, OH.

NOWAK, E. J., AND J. C. STORMONT, 1987. SCOPING MODEL CALCULATIONS OF THE RECONSOLIDATION OF CRUSHED SALT IN THE WIPP SHAFTS, SAND87-0879. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

POWERS, D. W., S. J. LAMBERT, S-E. SHAFFER, L. R. HILL, W. D. WEART, EDS, 1978. GEOLOGICAL CHARACTERIZATION REPORT, WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO, VOL. 1, SAND 78-1596. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

PUSCH, R., 1977. REQUIRED PHYSICAL AND MECHANICAL PROPERTIES OF BUFFER MASSES, KBS REPORT 03. KBS, STOCKHOLM, SWEDEN.

PUSCH, R., 1980A. WATER UPTAKE, MIGRATION AND SWELLING CHARACTERISTICS OF UNSATURATED AND SATURATED, HIGHLY COMPACTED BENTONITE, KBS REPORT 80-11. KBS, STOCKHOLM, SWEDEN

PUSCH, R., 1980B. SWELLING PRESSURE OF HIGHLY COMPACTED BENTONITE, KBS REPORT 80-13. KBS, STOCKHOLM, SWEDEN.

PUSCH, R., L. BORGESSON, A. FREDERIKSON, I. MARKSTROM, M. ERLSTROM, G. RAMQVIST, M. GRAY, W. COONS, AND M. ONOFREI, 1988. ROCK SEALING - INTERIM REPORT ON THE ROCK SEALING PROJECT (STAGE I), STRIPA PROJECT 88-11. SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO., STOCKHOLM, SWEDEN.

SAWYER, W. D., II, AND J. J. K. DAEMEN, 1987. EXPERIMENTAL ASSESSMENT OF THE SEALING PERFORMANCE OF BENTONITE BOREHOLE PLUGS, NUREG/CR-4995. PREPARED FOR U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC.

STORMONT, J. C., ED., 1986. DEVELOPMENT AND IMPLEMENTATION: TEST SERIES A OF THE SMALL-SCALE SEAL PERFORMANCE TESTS, SAND85-2602. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

STORMONT, J. C., AND C. L. HOWARD, 1986. DEVELOPMENT AND IMPLEMENTATION: TEST SERIES B OF THE SMALL-SCALE SEAL PERFORMANCE TESTS, SAND86-1329. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

STORMONT, J. C., AND C. L. HOWARD, 1987. DEVELOPMENT, IMPLEMENTATION, AND EARLY RESULTS: TEST SERIES C OF THE SMALL SCALE SEAL PERFORMANCE TESTS, SAND87-2203. SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM.

U.S. DEPARTMENT OF ENERGY, 1986. WIPP DESIGN VALIDATION FINAL REPORT, DOE-WIPP-86-010. BECHTEL NATIONAL INC., SAN FRANCISCO, CA.

WAKELEY, L. D., D. M. WALLEY, AND A. D. BUCK, 1986. DEVELOPMENT OF FRESHWATER GROUT SUBSEQUENT TO THE BELL CANYON TESTS (BCT). MISCELLANEOUS PAPER SL-86-2. U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MS

SNL APPROVALS		
ORG	DATE	APPROVALS
[illegible]	[illegible]	
[illegible]	[illegible]	
6346	11-28-89	
6346	11/28/89	

NEXT ASSEMBLY

APPLICATION

DR C. NORTHROP

CHK D L PULLIAM 11/21/89

ENG R JONES 11/21/89

APVD

Sandia National Laboratories

TITLE

TABLE OF SPECIFICATIONS

SIZE D

DWG NUMBER TRI-46-5

SCALE

SHEET 1 OF 1

Fig. 11. Table of Specifications

DISTRIBUTION

FEDERAL AGENCIES

U. S. Department of Energy, (5)
Office of Civilian Radioactive Waste Management
Attn: Deputy Director, RW-2
Associate Director, RW-10
Office of Program Administration and Resources Management
Associate Director, RW-20
Office of Facilities Siting and Development
Associate Director, RW-30
Office of Systems Integration and Regulations
Associate Director, RW-40
Office of External Relations and Policy
Forrestal Building
Washington, DC 20585

U. S. Department of Energy (3)
Albuquerque Operations Office
Attn: Bruce G. Twining
J. E. Bickel
R. Marquez, Director
Public Affairs Division
P.O. Box 5400
Albuquerque, NM 87185

U. S. Department of Energy
Attn: National Atomic Museum Library
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87185

U. S. Department of Energy (4)
WIPP Project Office (Carlsbad)
P.O. Box 3090
Carlsbad, NM 88221

U. S. Department of Energy
Research & Waste Management Division
Attn: W. R. Bibb, Director
P. O. Box E
Oak Ridge, TN 37831

U.S. Department of Energy
Richland Operations Office
Nuclear Fuel Cycle & Production Division
Attn: R. E. Gerton
P.O. Box 500
Richland, WA 99352

U. S. Department of Energy (1)
Attn: Edward Young
Room E-178
GAO/RCED/GTN
Washington, DC 20545

U. S. Department of Energy (6)
Office of Environmental Restoration and Waste Management
Attn: Jill Lytle, EM30
Mark Frei, EM-34 (3)
Mark Duff, EM-34
Clyde Frank, EM-50
Washington, DC 20585

U. S. Department of Energy (3)
Office of Environment, Safety and Health
Attn: Ray Pelletier, EH-231
Kathleen Taimi, EH-232
Carol Borgstrom, EH-25
Washington, DC 20585

U. S. Department of Energy (2)
Idaho Operations Office
Fuel Processing and Waste Management Division
785 DOE Place
Idaho Falls, ID 83402

U.S. Department of Energy
Savannah River Operations Office
Defense Waste Processing Facility Project Office
Attn: W. D. Pearson
P.O. Box A
Aiken, SC 29802

U.S. Environmental Protection Agency (2)
Attn: Ray Clark
Office of Radiation Programs (ANR-460)
Washington, DC 20460

U.S. Geological Survey
Branch of Regional Geology
Attn: R. Snyder
MS913, Box 25046
Denver Federal Center
Denver, CO 80225

U.S. Geological Survey
Conservation Division
Attn: W. Melton
P.O. Box 1857
Roswell, NM 88201

U.S. Geological Survey (2)
Water Resources Division
Attn: Kathy Peter
Suite 200
4501 Indian School, NE
Albuquerque, NM 87110

U.S. Nuclear Regulatory Commission (4)
Attn: Joseph Bunting, HLEN 4H3 OWFN
Ron Ballard, HLGP 4H3 OWFN
Jacob Philip
NRC Library
Mail Stop 623SS
Washington, DC 20555

Boards

Defense Nuclear Facilities Safety Board
Attn: Dermot Winters
Suite 675
600 E Street, NW
Washington, DC 20004

U. S. Department of Energy
Advisory Committee on Nuclear Facility Safety
Attn: Merritt E. Langston, AC21
Washington, DC 20585

Nuclear Waste Technical Review Board (2)
Attn: Dr. Don A. Deere
Dr. Sidney J. S. Parry
Suite 801
1111 18th Street, NW
Washington, DC 20006

Richard Major
Advisory Committee on Nuclear Waste
Nuclear Regulatory Commission
7920 Norfolk Avenue
Bethesda, MD 20814

STATE AGENCIES

Environmental Evaluation Group (3)
Attn: Library
Suite F-2
7007 Wyoming Blvd., N.E.
Albuquerque, NM 87109

New Mexico Bureau of Mines and Mineral Resources (2)
Attn: F. E. Kottolowski, Director
J. Hawley
Socorro, NM 87801

NM Department of Energy & Minerals
Attn: Librarian
P.O. Box 2770
Santa Fe, NM 87501

NM Environmental Improvement Division
Attn: Deputy Director
1190 St. Francis Drive
Santa Fe, NM 87503

LABORATORIES/CORPORATIONS

Battelle Pacific Northwest Laboratories (6)
Attn: D. J. Bradley
J. Relyea
R. E. Westerman
S. Bates
H. C. Burkholder
L. Pederson
Battelle Boulevard
Richland, WA 99352

Savannah River Laboratory (6)
Attn: N. Bibler
E. L. Albenisius
M. J. Plodinec
G. G. Wicks
C. Jantzen
J. A. Stone
Aiken, SC 29801

Savannah River Plant
Attn: Richard G. Baxter
Building 704-S
Aiken, SC 29808

George Dymmel
SAIC
101 Convention Center Dr.
Las Vegas, NV 89109

INTERA Technologies, Inc. (4)
Attn: G. E. Grisak
J. F. Pickens
A. Haug
A. M. LeVenue
Suite #300
6850 Austin Center Blvd.
Austin, TX 78731

INTERA Technologies, Inc.
Attn: Wayne Stensrud
P.O. Box 2123
Carlsbad, NM 88221

IT Corporation (2)
Attn: R. F. McKinney
J. Myers
Regional Office - Suite 700
5301 Central Avenue, NE
Albuquerque, NM 87108

IT Corporation (2)
Attn: D. E. Deal
P.O. Box 2078
Carlsbad, NM 88221

Charles R. Hadlock
Arthur D. Little, Inc.
Acorn Park
Cambridge, MA 02140-2390

Los Alamos Scientific Laboratory
Attn: B. Erdal, CNC-11
Los Alamos, NM 87545

Oak Ridge National Laboratory (4)
Attn: R. E. Blanko
E. Bondietti
C. Claiborne
G. H. Jenks
Box 2009
Oak Ridge, TN 37831

RE/SPEC, Inc.
Attn: W. Coons
P. F. Gnirk
P.O. Box 14984
Albuquerque NM 87191

RE/SPEC, Inc. (7)
Attn: L. L. Van Sambeek
D. B. Blankenship
G. Callahan
T. Pfeifle
J. L. Ratigan
P. O. Box 725
Rapid City, SD 57709

Center for Nuclear Waste
Regulatory Analysis (4)
Attn: P. K. Nair
Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78228-0510

Science Applications
International Corporation
Attn: Howard R. Pratt,
Senior Vice President
10260 Campus Point Drive
San Diego, CA 92121

Science Applications
International Corporation
Attn: Michael B. Gross
Ass't. Vice President
Suite 1250
160 Spear Street
San Francisco, CA 94105

Systems, Science, and Software (2)
Attn: E. Peterson
P. Lagus
Box 1620
La Jolla, CA 92038

Westinghouse Electric Corporation (7)
Attn: Library
Lamar Trego
W. P. Poirer
W. R. Chiquelin
V. F.Likar
D. J. Moak
R. F. Kehrman
P. O. Box 2078
Carlsbad, NM 88221

Weston Corporation (1)
Attn: David Lechel
Suite 1000
5301 Central Avenue, NE
Albuquerque, NM 87108

UNIVERSITIES

University of Arizona
Attn: J. G. McCray
Department of Nuclear Engineering
Tucson, AZ 85721

University of New Mexico (2)
Geology Department
Attn: D. G. Brookins
Library
Albuquerque, NM 87131

Pennsylvania State University
Materials Research Laboratory
Attn: Della Roy
University Park, PA 16802

Texas A&M University
Center of Tectonophysics
College Station, TX 77840

G. Ross Heath
College of Ocean
and Fishery Sciences
University of Washington
Seattle, WA 98195

INDIVIDUALS

Dennis W. Powers
Star Route Box 87
Anthony, TX 79821

LIBRARIES

Thomas Brannigan Library
Attn: Don Dresp, Head Librarian
106 W. Hadley St.
Las Cruces, NM 88001

Hobbs Public Library
Attn: Ms. Marcia Lewis, Librarian
509 N. Ship Street
Hobbs, NM 88248

New Mexico State Library
Attn: Ms. Ingrid Vollenhofer
P.O. Box 1629
Santa Fe, NM 87503

New Mexico Tech
Martin Speere Memorial Library
Campus Street
Socorro, NM 87810

Pannell Library
Attn: Ms. Ruth Hill
New Mexico Junior College
Lovington Highway
Hobbs, NM 88240

WIPP Public Reading Room
Attn: Lee Hubbard, Head Librarian
Carlsbad Municipal Library
101 S. Halagueno St.
Carlsbad, NM 88220

Government Publications Department
General Library
University of New Mexico
Albuquerque, NM 87131

THE SECRETARY'S BLUE RIBBON PANEL ON WIPP

Dr. Thomas Bahr
New Mexico Water Resources Institute
New Mexico State University
Box 3167
Las Cruces, NM 88003-3167

Mr. Leonard Slosky
Slosky and Associates
Suite 1400
Bank Western Tower
1675 Tower
Denver, Colorado 80202

Mr. Newal Squyres
Eberle and Berlin
P. O. Box 1368
Boise, Idaho 83701

Dr. Arthur Kubo
Vice President
BDM International, Inc.
7915 Jones Branch Drive
McLean, VA 22102

Mr. Robert Bishop
Nuclear Management Resources Council
Suite 300
1776 I Street, NW
Washington, DC 20006-2496

NATIONAL ACADEMY OF SCIENCES, WIPP PANEL

Dr. Charles Fairhurst, Chairman
Department of Civil and
Mineral Engineering
University of Minnesota
500 Pillsbury Dr. SE
Minneapolis, MN 55455

Dr. John O. Blomeke
Route 3
Sandy Shore Drive
Lenoir City, TN 37771

Dr. John D. Bredehoeft
Western Region Hydrologist
Water Resources Division
U.S. Geological Survey (M/S 439)
345 Middlefield Road
Menlo Park, CA 94025

Dr. Karl P. Cohen
928 N. California Avenue
Palo Alto, CA 94303

Dr. Fred M. Ernsberger
250 Old Mill Road
Pittsburgh, PA 15238

Dr. Rodney C. Ewing
Department of Geology
University of New Mexico
200 Yale, NE
Albuquerque, NM 87131

B. John Garrick
Pickard, Lowe & Garrick, Inc.
2260 University Drive
Newport Beach, CA 92660
John W. Healy
51 Grand Canyon Drive
Los Alamos, NM 87544

Leonard F. Konikow
U.S. Geological Survey
431 National Center
Reston, VA 22092

Jeremiah O'Driscoll
505 Valley Hill Drive
Atlanta, GA 30350

Dr. D'Arcy A. Shock
233 Virginia
Ponca City, OK 74601

Dr. Christopher G. Whipple
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

Dr. Peter B. Myers, Staff
Director
National Academy of Sciences
Committee on Radioactive
Waste Management
2101 Constitution Avenue
Washington, DC 20418

Ina Alterman
Board on Radioactive Waste
Management
GF462
2101 Constitution Avenue
Washington, D. C. 20418

FOREIGN ADDRESSES

Studiecentrum Voor Kernenergie
Centre D'Energie Nucleaire
Attn: Mr. A. Bonne
SCK/CEN
Boeretang 200
B-2400 Mol
BELGIUM

Atomic Energy of Canada, Ltd. (2)
Whiteshell Research Estab.
Attn: Peter Haywood
John Tait
Pinewa, Manitoba, CANADA
ROE 1LO

Dr. D. K. Mukerjee
Ontario Hydro Research Lab
800 Kipling Avenue
Toronto, Ontario, CANADA
M8Z 5S4

Mr. D. Alexandre, Deputy Director
ANDRA
31, Rue de la Federation
75015 Paris, FRANCE

Mr. Jean-Pierre Olivier
OECD Nuclear Energy Agency
Division of Radiation Protection
and Waste Management
38, Boulevard Suchet
75016 Paris, FRANCE

Claude Sombret
Centre D'Etudes Nucleaires
De La Vallee Rhone
CEN/VALRHO
S.D.H.A. BP 171
30205 Bagnols-Sur-Ceze
FRANCE

Bundesministerium fur Forschung und
Technologie
Postfach 200 706
5300 Bonn 2
FEDERAL REPUBLIC OF GERMANY

Bundesanstalt fur Geowissenschaften
und Rohstoffe
Attn: Michael Langer
Postfach 510 153
3000 Hannover 51
FEDERAL REPUBLIC OF GERMANY

Hahn-Meitner-Institut fur
Kernforschung
Attn: Werner Lutze
Glienicker Strasse 100
100 Berlin 39
FEDERAL REPUBLIC OF GERMANY

Institut fur Tieflagerung (4)
Attn: K. Kuhn
Theodor-Heuss-Strasse 4
D-3300 Braunschweig
FEDERAL REPUPLIC OF GERMANY

Kernforschug Karlsruhe
Attn: K. D. Closs
Postfach 3640
7500 Karlsruhe
FEDERAL REPUBLIC OF GERMANY

Physikalisch-Technische Bundesanstalt
Attn: Peter Brenneke
Postfach 33 45
D-3300 Braunschweig
FEDERAL REPUBLIC OF GERMANY

D. R. Knowles
British Nuclear Fuels, plc
Risley, Warrington, Cheshire WA3 6AS
1002607 GREAT BRITAIN

Shingo Tashiro
Japan Atomic Energy Research
Institute
Tokai-Mura, Ibaraki-Ken
319-11 JAPAN

Netherlands Energy Research
Foundation
ECN (2)
Attn: Tuen Deboer, Mgr.
L. H. Vons
3 Westerduinweg
P.O. Box 1
1755 ZG Petten, THE NETHERLANDS

DISTRIBUTION

Svensk Karnbransleforsorjning AB
Attn: Fred Karlsson
Project KBS
Karnbranslesakerhet
Box 5864
10248 Stockholm, SWEDEN

SANDIA INTERNAL

1510	J. W. Nunziato
1520	C. W. Peterson
1521	R. D. Krieg
1521	J. G. Arguello
1521	H. S. Morgan
3141	S. A. Landenberger (5)
3151	W. I. Klein (3)
3154-1	C. L. Ward, (8) for DOE/OSTI
6000	D. L. Hartley
6232	W. R. Wawersik
6233	J. C. Eichelberger
6233	J. L. Krumhansl
6300	R. W. Lynch
6310	T. O. Hunter
6313	T. Blejwas
6340	W. D. Weart
6340	S. Y. Pickering
6341	R. C. Lincoln
6341	Staff (7)
6341	Sandia WIPP Central Files (100)
6342	D. R. Anderson
6342	Staff (11)
6343	T. M. Schultheis (6)
6344	E. Gorham
6344	Staff (8)
6345	A. R. Lappin
6345	Staff (8)
6346	J. R. Tillerson (6)
6346	E. J. Nowak (10)
6346	T. M. Torres (6)
6346	Staff (4)
6350	W. C. Luth
8524	J. A. Wackerly (SNLL Library)
9300	J. E. Powell
9310	J. D. Plimpton
9320	M. J. Navratil
9325	R. L. Rutter
9325	J. T. McIlmoyle
9330	J. O. Kennedy
9333	O. Burchett
9333	J. W. Mercer
9334	P. D. Seward

☆ U.S. GOVERNMENT PRINTING OFFICE: 1990—773-118/20071

Org.	Bldg.	Name	Rec'd by	Org.	Bldg.	Name	Rec'd by

Sandia National Laboratories