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Geotechnical Analysis Report

July 1992 - June 1993

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Waste Isolation Pilot Plant

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FOREWORD AND ACKNOWLEDGMENTS

This report provides an assessment of the geotechnical status of the Waste Isolation Pilot Plant (WIPP). During the construction of the principal underground access and experimental areas, reporting was on a quarterly basis. Since 1987, reporting has been carried out annually because additional excavations will take place gradually over an extended period. This report presents and analyzes data collected up to June 30, 1993.

The format of the Geotechnical Analysis Report was selected to meet the needs of several audiences. This report focuses on the geotechnical performance of the various underground facilities including the shafts, shaft stations, access drifts, test rooms, and waste storage areas. The results of excavation effects investigations, stratigraphic mapping, and other geologic studies are also included. The report provides an evaluation of the geotechnical aspects of performance in the context of the relevant design criteria and also describes the techniques used to acquire the data and the performance history of the instruments. The depth and breadth of the evaluation for the different underground facilities varies according to the types and quantities of data that are available, and the complexity of the recorded geotechnical responses.

Documentation of data in graph format and the history of the instruments in tables is available and can be provided upon request. Data files will be made available at nominal cost upon request to the U.S. Department of Energy (DOE) at the following address:

U.S. Department of Energy
WIPP Project Office
P.O. Box 3090
Carlsbad, NM 88221
Attention: George Dials

The Geotechnical Analysis Report is a multiple-author report that was prepared by Westinghouse Waste Isolation Division for the U.S. Department of Energy, Carlsbad Area Office, Carlsbad, New Mexico. Work supported by U.S. Department of Energy under contract No. DE-AC04-86AL31950

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List of Acronyms/Abbreviations

C&SH	Construction and Salt Handling
DOE	U.S. Department of Energy
GIS	Geomechanical Instrumentation System
LTC	Local Termination Cabinets
SPDV	Site and Preliminary Design Validation
WIPP	Waste Isolation Pilot Plant

1.0 Introduction

The geotechnical data from the underground excavations at the Waste Isolation Pilot Plant are interpreted and presented in the Geotechnical Analysis Report. The data are used to characterize conditions, assess design assumptions, and understand and predict the performance of the underground excavations during operations. The data are obtained as part of a regular monitoring program and excludes data from tests performed by Sandia National Laboratories, the Scientific Advisor to the project in support of performance assessment studies.

Geotechnical Analysis Reports have been prepared routinely and made available to the public since 1983. During the Site and Preliminary Design Validation Program, the Architect/-Engineer for the project produced the reports on a quarterly basis to document the geomechanical performance during construction of the underground. Upon completion of the construction phase of the project in 1987, the reports have been prepared annually by the Management and Operating Contractor for the facility. This report describes the performance and conditions of selected areas from July 1, 1992, to June 30, 1993.

1.1 Location and Description

The Waste Isolation Pilot Plant is located in southeastern New Mexico about 30 miles east of Carlsbad (Figure 1-1). The surface facilities have been built on the flat to gently rolling hills that are characteristic of the Los Medanos (sand hills) area. The underground facilities are being excavated approximately 2,150 feet beneath the surface in the Salado Formation. A schematic view of the surface and underground facilities at the Waste Isolation Pilot Plant site are shown in Figure 1-2.

1.2 Mission

The Waste Isolation Pilot Plant was authorized by Congress in 1979 (Public Law 96-164) to provide "...a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." The Waste Isolation Pilot Plant is intended to receive, handle, and permanently dispose of transuranic waste. To fulfill this mission, the U.S. Department of Energy is constructing a full scale facility to

Figure 1-2
Schematic of Underground Facilities

demonstrate both technical and operational principles of the permanent storage/disposal of transuranic waste. Technical aspects are those concerned with the design, construction, and performance of the subsurface structures. Operational aspects refer to the receiving, handling, and emplacement of transuranic waste in salt. The facility is also designed for in-situ studies and experiments in salt.

1.3 Development Status

To fulfill its mission, the Department of Energy is developing the Waste Isolation Pilot Plant in a phased manner. The Site and Preliminary Design Validation phase began in 1980 with the purpose of characterizing the site and obtaining geotechnical data to determine whether site characteristics and design were suitable for a permanent disposal facility. During this phase, the Salt Handling Shaft, a Ventilation Shaft, a drift to the southernmost extent of the proposed waste storage area, a four-room test panel, and access drifts were excavated. Surface-based geological and hydrological investigations were also conducted. The data obtained from the Site and Preliminary Design Validation investigations were reported in the Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program (DOE, 1983).

Based on the favorable results of the Site and Preliminary Design Validation investigations, additional activities were started. These included construction of surface structures, conversion of the Ventilation Shaft for use as the Waste Shaft, excavation of the Exhaust Shaft, development of additional access drifts to the waste storage area, and excavation of experimental rooms to support research and development activities. Geotechnical data acquired during this phase were used to evaluate the performance of the excavations in the context of established design criteria (DOE, 1984). Results of these evaluations were reported in Geotechnical Field Data and Analysis Reports (DOE, 1985; DOE, 1986a) and were summarized in the Design Validation Final Report (DOE, 1986b).

The Design Validation Final Report concluded that the facilities including waste storage areas could be developed and operated to fulfill the long-term mission of the Waste Isolation Pilot Plant. However, some modifications to the reference design were proposed in order to meet the requirements for the life of openings during an initial demonstration phase when retrievability of the waste remained an option.

The original design for the waste storage rooms at the Waste Isolation Pilot Plant provided a limited time in which to mine the salt and emplace waste. Each panel, consisting of seven storage rooms, was scheduled to be mined, filled with waste containers, and backfilled in less than five years before being sealed. Field studies, as part of the Site and Preliminary Design Validation Program, showed that unsupported openings of a typical storage room configuration at the Waste Isolation Pilot Plant would remain stable and that closure from creep would not impact equipment clearances during the five year period following excavation. The information from these studies provided the validation of the design of openings for the permanent disposal of waste under routine operations.

Panel 1 was developed to receive waste for a demonstration and test phase that was scheduled to start in October 1988. This original plan consisted of the storage of drums of contact handled transuranic waste in rooms for a period of five years. During this time and immediately following it, the rooms were to be inaccessible, but the option to reenter was to be maintained so that the waste could be removed, if required. To assist with the possible reentry, ten-foot roofbolts were installed in the rooms in Panel 1 to enhance roof stability.

The demonstration phase was deferred, and the experimental test program was modified to use contact handled transuranic waste in bin-scale tests, planned for Room 1, Panel 1. This program was to investigate the repository conditions that would result from the different types of waste that will be disposed of in the underground facility. The decision to use Room 1, Panel 1 for these bin-scale tests was made in June 1989, when initial waste receipt was anticipated in 1990. For the planned on-site bin-scale test, an additional seven years of useful life was required for the test room(s) in Panel 1. Panel 1 test room(s) were required to provide essentially uninterrupted accessibility throughout the test phase. These changing requirements led to more stringent criteria for roof stability. In late 1993, the test program was relocated off site with a new anticipated date for first waste receipt in 1998. As a result of relocating the test program off site, Panel 1 is in stand-by status.

1.4 Purpose and Scope of Geomechanical Monitoring Program

The purpose of the geomechanical monitoring program is to provide in-situ data to support:

- Early detection of conditions that could compromise operational safety
- Evaluation of room closure to ensure retrievability of waste

- Guidance for design modifications and remedial actions
- Data for interpreting the in-situ behavior of underground openings, in comparison with established design criteria.

The geomechanical instrumentation used in the Waste Isolation Pilot Plant facility provides data which are collected, processed, and stored for analysis. The following discussion briefly describes the major components of the Geomechanical Instrumentation System (GIS) and does not include instrumentation monitored by Sandia National Laboratories.

1.4.1 Instrumentation

Instruments installed for measuring the geomechanical response of the shafts and other underground openings include convergence points, convergence meters, borehole extensometers, rockbolt load cells, pressure cells, strain gauges, piezometers, and joint meters. A summary of the geomechanical instrumentation specifications is presented in Table 1-1.

1.4.2 Data Acquisition

The individual instruments that comprise the GIS are either read manually using portable devices or remotely by polling devices located on the surface. Remotely read instruments are connected to one of ten dataloggers located underground and readings are collected by referencing the appropriate identifier code. Upon completion of a verification process, as described in WIPP procedures, the data are transferred to a computer database. The manual reading devices are taken to the instrument locations underground, and the instruments are read. The data are recorded on an appropriate data sheet and later entered into database files where they are combined with the remotely acquired readings.

The underground data acquisition system consists of instruments, polling devices, and communications network. The polling devices are installed in underground Local Termination Cabinets (LTC) to query each individual instrument. The polling devices are connected via datalink cables and modems to the surface datalogging computer. Each polling device consists of a remote switching station and readout unit that is connected to the instruments throughout the facility. The surface datalogging computer utilizes datalink cables with modem interfaces to receive the instrument readings from the polling units.

Table 1-1
Geomechanical Instrumentation Specifications

Instrument Type	Measured	Range	Resolution
Sonic Probe Borehole Extensometers	Cumulative Deformation	0-2 inches	+/- 0.001 in.
Convergence Points	Cumulative Deformation	2-50 feet	+/- 0.001 in.
Wire Convergence Meters	Cumulative Deformation	0-3 feet	+/- 0.004 in.
Sonic Probe Convergence Meters	Cumulative Deformation	0-2.5 feet	+/- 0.001 in.
Embedded Strain Gauges	Cumulative Strain	0-3000 uin./in.	+/- 1uin./in.
Spot-Welded Strain Gauges	Cumulative Strain	0-2500 uin./in.	+/- 1 uin./in.
Rockbolt Load Cells	Load	0-50 tons	+/- 40 lbs.
Earth Pressure Cells	Pressure	0-10 psi	+/- 0.05 psi
Piezometers	Fluid Pressure	0-500 psi	+/- 0.5 psi
Joint Meters	Cumulative Deformation	0-4 inches	+/- 0.002 in.
Vibrating WireBorehole Extensometer	Cumulative Deformation	0-4 inches	0.002 in.
Rod Extensometers	Cumulative Deformation	0-6 inches	0.001 in.

Whether acquired manually or automatically, GIS data are entered into the database files of the GIS data processing system. The processing system is programmed to enter, reduce, and transfer the instrumentation data to permanent storage files. Utilizing dBase IV software, the datalogging programs and the GIS data processing system programs are accessed via a personal computer located on the surface at the WIPP site. Additional programming allows access to these permanent storage files for tabular reporting and graphical plotting.

The datalogging computer capabilities allow the GIS operator to remotely access a polling device from either an intermediate mode or a predefined parameters mode. The intermediate mode yields a printout and/or test field of the readings from the polled device. The predefined parameters mode yields a printout and the test file update of the permanent polling file.

1.4.3 Data Evaluation

Information regarding data plots are available upon request and can be found in previous Geotechnical Field Data and Analysis Reports.

Closure measurements are taken at convergence points that are acquired manually and remotely with convergence meters. The plots are presented as total displacement with time.

Extensometers provide relative displacement data acquired from remotely and manually read sonic probe and vibrating wire extensometers. Relative displacement is the measure of movement in the rock strata of the borehole from various depths and compared to a reference point. The ground displacement is monitored over time and plotted as either surface displacement or closure versus time.

Borehole extensometers are used to determine the relative movement of the rock mass around the openings. With this instrument, rods are anchored in a hole at various depths. The deepest anchor is assumed to be fixed in undisturbed ground. A relative displacement is determined by referencing the other anchors to the deepest anchor. Typically, the plots will show increasing ground movement near the opening, i.e., the collar of the hole.

Rockbolt load cells are used to determine the ground loading and the effectiveness of roofbolts. Plots consist of load, in kips versus time for each instrumented bolt.

Earth pressure cells and strain gauges are used to determine the loads in and around the shaft liners and are depicted in time-based plots. Monitoring of these instruments indicates whether there is any stress buildup in the shaft lining systems.

Piezometers are used to measure the gauge pressure of ground water. They are installed in the shafts at varying elevations to monitor the hydraulic head acting on the shaft liners. Plots from piezometers are presented as pressure versus time.

Joint meters are currently installed underground in the S1950 drift and the E0 drift. They are installed perpendicular to a crack and monitor the separation of the crack over time. Plots are presented as displacement versus time.

1.4.4 Data Errors

As described above, GIS data are processed through a comprehensive database management system. These steps are performed according to established quality control procedures approved by quality assurance. Whether acquired manually or remotely, GIS data are processed and permanently stored according to approved procedures. There are several possible explanations why these readings occur.

- The measuring device was misread.
- The reading was recorded incorrectly.
- The measuring device was not functioning within specifications.

2.0 Geology

A generalized stratigraphy of the geology of the region surrounding WIPP is given in Figure 2-1. This geologic summary is taken from Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant (DOE/WIPP 90-051).

2.1 Mescalero Caliche

Many of the surface structures at WIPP are found on top of the Mescalero Caliche, about 10 feet thick. The overall degree of carbonate induration generally decreases downward and the upper part displays a well developed laminar texture. Nodules and stringers of carbonate become more prominent downward, and the middle part of the caliche is dominated by these textures. Clastic material increases downward. Irregular zones containing sandstone are found toward the middle of the caliche and become larger and more prominent downward. The lower part of the caliche is dominantly a carbonate cemented sandstone. The contact between the Mescalero Caliche and Gatuna Formation is gradational.

2.2 Gatuna Formation

The Gatuna Formation, about 13 feet thick, occurs as a thin veneer of sandstone that is light red and mottled with dark stains. Carbonate occurs as stringers and concretions. Clay-sized materials locally appear translocated. Some pebble-sized clasts of sandstone are probably derived from the underlying Santa Rosa Formation. The contact between the Gatuna and the Santa Rosa Formation is sharp and erosional.

2.3 Santa Rosa Formation

The Santa Rosa Formation, about 25 feet thick, occurs as an erosional wedge of calcareous interbedded sandstone, siltstone, and claystone which is moderately well indurated to soft. The Santa Rosa consists of alternating sequences of channel deposits with fluvial bar sequences and, less commonly, mudstone or claystone. The fluvial bar sequences exhibit planar laminae with low angle, tangential cross-laminae. Ripple cross-laminae often top the bar sequences. Fissile claystone is present as thin beds. Rip-up clasts occur locally. The contact between the Santa Rosa and the Dewey Lake Redbeds is sharp and erosional.

Figure 2-1
General Geologic Cross Section

2.4 Dewey Lake Redbeds

The Dewey Lake Redbeds are about 475 feet thick and consist of interbedded siltstone, fine sandstone, mudstone, and claystone. The Dewey Lake can be subdivided on the basis of grain size and sedimentary structures into 1) an upper sequence deposited from a fine-grained, ephemeral fluvial system and 2) a lower sequence deposited in saline mud flat/mud flat environments. Gypsum filled fractures are abundant throughout most of the Dewey Lake and are at least partly syndepositional. The Dewey Lake represents a transition from the marine-influenced evaporite deposition of the Rustler to fluvial deposition on a broad, low-relief, fluvial plain. The contact with the Rustler Formation is sharp, undulatory, and erosional.

2.5 Rustler Formation

The Rustler Formation, about 300 feet thick, is subdivided into five stratigraphic sequences: Forty-niner, Magenta, Tamarisk, Culebra, and an unnamed lower member.

The Forty-niner, about 60 feet thick, consists of two anhydrite beds that sandwich a thinner, 15 feet thick, mudstone bed.

The Magenta Dolomite Member, about 25 feet, is composed of light gray to dark brown gypsiferous and arenaceous dolomite with abundant sedimentary structures due to traction deposits.

Like the Forty-niner Member, the Tamarisk Member of the Rustler Formation consists of an upper and lower anhydrite bed that sandwich a thinner, about 10 feet thick, mudstone bed. The Tamarisk varies from 100 to 170 feet around the WIPP site.

The Culebra Dolomite Member is the most transmissive hydrologic unit and is a laterally extensive marker bed within the Rustler Formation. The Culebra is an argillaceous dolomicrite containing abundant open and gypsum-filled porosity. The upper zone contains organic-rich claystone and carbonate.

The unnamed lower member, approximately 130 feet thick, consists of clastic sediments with subordinated halite, anhydrite, and polyhalite. Neither significant solution nor erosion along the basal contact is exposed in the shafts.

2.6 Salado Formation

The Salado Formation consists of nearly 2000 feet of evaporites and is subdivided into three informal members: an unnamed upper member, a middle member locally designated the McNutt potash zone, and an unnamed lower member. Each of the members contain similar amounts of halite, anhydrite, and polyhalite and are differentiated on the basis of other potassium and magnesium-bearing minerals. The upper and lower members generally lack these minerals while the middle member (McNutt potash zone) contains a relative abundance of these minerals.

Halite is the most abundant mineral in the Salado and occurs in thick beds intercalated with thinner beds of polyhalite or anhydrite (Holt and Powers, 1984, 1986). Salado halite is rarely pure and usually contains minor and trace amounts of clay, anhydrite, or polyhalite (Powers et al., 1978; Holt and Powers, 1984, 1986). Halite crystal size and morphology varies considerably, and various large- and small-scale sedimentary structures are abundant throughout all of the Salado halite.

The underground excavations at WIPP are located within the Salado at 2,150 feet below the surface. The underground facility comprised of a storage horizon and an experimental horizon, lies within a 40-foot unit of laterally continuous stratigraphic sequences consisting of halite, argillaceous halite, and polyhalitic halite (Figure 2-2).

2.6.1 Storage Horizon

Anhydrite "a" is located about 13 feet above the roof and is underlain by Clay H; Anhydrite "b" is located about 6.5 feet above the roof and is underlain by Clay G. A thin layer, Clay F is found in the ribs about two feet below the roof.

A 20- to 32-inch thick, bed of anhydrite, identified as Marker Bed 139, typically lies about five feet below the floor throughout the storage horizon. Lateral variability in composition and thickness exist within this anhydrite bed at both repository and regional scale. The variability in thickness, up to six inches, has been observed in four inch diameter cores (Holt and Powers, 1990). The bottom of Marker Bed 139 is subhorizontal and underlain by Clay E.

Marker Bed 139 and the clay layers have a significant impact on the mechanical performance

Figure 2-2
Generalized Stratigraphic Column

of excavations. The clay layers provide surfaces along which slip and separation can occur, whereas Marker Bed 139 acts as a brittle unit that does not deform plastically. In addition, the undulating top of the marker bed resists shear movement along the interface with the overlying salt.

2.6.2 Experimental Horizon

The experimental horizon is 18 feet above the storage horizon. Clay I typically occurs at 4.5 to 5 feet above the roof in the access drifts. The floor occurs at Anhydrite "b" and Anhydrite "a" is visible in the ribs or roof.

As in the storage horizon, the clay layers have a significant impact on the mechanical deformation of the experimental excavations.

2.7 Castile Formation

The Castile Formation underlies the Salado Formation. The Castile Formation is approximately 1200-feet thick and consists of thick units of laminated anhydrite, carbonate, and halite.

2.8 Bell Canyon Formation

The Bell Canyon Formation underlies the Castile Formation. The Bell Canyon Formation is the upper most formation in the Delaware Mountain Group. Interbedded sandstone, shale, and limestone compose the major lithologies of this formation.

3.0 Performance of Shafts and Keys

3.1 Salt Handling Shaft

The first construction activity undertaken during the Site and Preliminary Design Validation (SPDV) work was the excavation of the Exploratory Shaft, subsequently designated the Construction and Salt Handling (C&SH) Shaft and currently designated the Salt Handling Shaft (Figure 1-2). The shaft was drilled from July 4 to October 24, 1981. Geologic mapping was conducted from March through May 1982 (DOE, 1983). Figure 3-1 presents the generalized stratigraphy of the Salt Handling Shaft.

The Salt Handling Shaft is lined with steel casing and has a 10-foot inside diameter from the ground surface to a depth of 846 feet. The 10-foot diameter extends through the concrete shaft key to a depth of 880 feet. The nominal shaft diameter is 12 feet from the key to the bottom of the shaft at 2,298 feet and is unlined. The steel liner thickness increases with depth, starting at 0.62-inch thick at the top and increasing to 1.5 inches thick at the key. Cement grout holds the liner in place. The shaft key is a 37.5-foot-long reinforced-concrete structure at the base of the steel liner.

3.1.1 Modifications to Excavation

Shaft inspections are conducted by mining operations personnel on a weekly basis. The shaft is in satisfactory condition.

3.1.2 Instrumentation

Installation of geomechanical instrumentation in the Salt Handling Shaft occurred in April and July 1982 (Figures 3-2 and 3-3). The instrumentation consisted of extensometers, piezometers, earth pressure cells, strain gages, and radial convergence points.

Instruments were manually read until October 1983 when a remote data acquisition system was installed. The instruments are now read remotely with the exception of nine radial convergence points located at 296', 454', and 814'.

The geomechanical instrumentation in the lined portion of the Salt Handling Shaft has performed poorly since its second year of operation. Shaft instrumentation components were

SALT HANDLING SHAFT

EXPLANATION

SAND AND SANDSTONE		HALITE	
MUDSTONE AND SILTSTONE		DOLOMITE	
ANHYDRITE		CONCRETE	

NOTES

1. ALL ROCKS BELOW DOCKUM GROUP ARE PERMIAN IN AGE
2. ALL LEVELS ARE MEASURED FROM COLLAR AT 3410 FEET MSL
3. MB=MARKER BED

00648

Figure 3-1
Generalized Salt Handling Shaft Stratigraphy

Figure 3-2
Salt Handling Shaft Instrumentation (without Shaft Key)

**Figure 3-3
Salt Handling Shaft Key Instrumentation**

damaged by construction related activities, including salt handling (hoisting) and movement of construction materials. Falling objects and the accumulation of rainfall have caused several failures to junction boxes, termination cabinets, cables, and convergence points.

Damage to the electronics in LTC 1, which contained the automatic polling device for the lined section of this shaft, has resulted in some loss of instrumentation data. This instrumentation includes piezometers, earth pressure cells, and strain gauges. Please refer to Geotechnical Field Data and Analysis Reports prior to July 1992 for information on this data.

Installation of nine multi-position borehole extensometers in the Salt Handling Shaft occurred July 6 through 8, 1982. These instruments are arranged in three instrument arrays at levels 1073', 1564', and 2057' (Figure 3-2). An extensometer at level 2057' is the only functioning extensometer and has been read intermittently since 1982. The last reading was June 9, 1993, with a total collar displacement of 0.56 inches since installation.

3.2 Waste Shaft

During construction activity, undertaken as part of the SPDV program, a six-foot diameter ventilation shaft was excavated from December 1981 through February 1982 in order to allow a two-shaft underground air circulation scheme to function. From October 11, 1983 through June 11, 1984, this shaft was enlarged to 20- to 23-foot diameter and lined, then renamed the Waste Shaft. Geologic mapping was conducted during shaft enlargement from December 9, 1983 through June 5, 1984 (Holt and Powers, 1984). The generalized stratigraphy of the waste shaft is presented in Figure 3-4.

The waste shaft is lined with unreinforced concrete and has a 19-foot inside diameter from the ground surface to 837 feet. The liner thickness increases with depth from 10 inches at the surface to 20 inches at the key. The Waste Shaft key is 63 feet long, 4.25 feet thick and constructed of reinforced concrete. The bottom of the key is at 900 feet. The section of the shaft below the key is 20 feet in diameter and enlarges to 23 feet just above the shaft station. The 23-foot diameter extends to a depth of approximately 2,272 feet.

3.2.1 Modifications to Excavation

Shaft inspections are conducted on a weekly basis by mining operations personnel. The

WASTE SHAFT

LEGEND

SAND AND SANDSTONE		HALITE	
MUDSTONE AND SILTSTONE		DOLOMITE	
ANHYDRITE		CONCRETE	

NOTES

1. ALL ROCKS BELOW DOCKUM GROUP ARE PERMIAN IN AGE
2. ALL LEVELS ARE MEASURED FROM COLLAR AT 3400 FEET MSL.
3. MB=MARKER BED

Figure 3-4
Generalized Waste Shaft Stratigraphy

condition of the shaft is satisfactory. A cable-support ground control system was installed in the eastern brow of the waste shaft.

3.2.2 Instrumentation

The Waste Shaft was equipped with geomechanical instrumentation from August 27, through September 10, 1984. The instrumentation configuration is presented in Figures 3-5 and 3-6.

Geomechanical instrumentation in this shaft are connected to LTC-15, which was installed at the facility level to avoid the damage and accessibility problems that occur in the shaft. Manually read convergence points are no longer accessible due to obstructions in the area. Since December 15, 1984, LTC-15 has been connected to the datalogging computer. An inspection of this shaft on June 16, 1985, indicated visible damage to the wiring for two piezometers and one earth pressure cell. During preliminary hoist installation work, junction boxes in the lined section of this shaft were found to interfere with the conveyance counterweight, and were removed in August 1986. Wiring damage may also have caused a loss of data from three borehole extensometers in the unlined section of this shaft. Repair and reinstallation work on the damaged instruments and components was completed prior to June 30, 1988.

3.2.2.1 Extensometers

Nine multi-position borehole extensometers were installed in the Waste Shaft from August, 31, through September 5, 1984. These instruments were arranged in arrays at levels 1071', 1566', and 2059' as shown in Figure 3-5. Initial readings were taken manually, and subsequent readings were taken by the datalogging computer. The orientation diagram on each plot shows anchor depth measured from the surface of the shaft wall.

Approximately 1.2 inches of displacement relative to the deepest anchor occurred in extensometer 31X-GE-00209 located at level 2059'. Extensometer 31X-GE-00203 located at level 1071' shows a total relative displacement of 0.15 inches, which is the least amount of displacement recorded from the extensometers in the Waste Shaft.

3.2.2.2 Piezometers

Twelve piezometers were installed in the lined section of the Waste Shaft on September 7, and 8, 1984. Piezometer arrays were installed at levels 532', 611', 669', 717', 758', and

Figure 3-5
Waste Shaft Instrumentation (without Shaft Key)

PRESSURE CELL ORIENTATION
AT ELEV. 2543 FT (LEVEL 866 FT)

TOP OF KEY
ELEV. 2575 (LEVEL 834)
ELEV. 2564 (LEVEL 845)

ELEV. 2543 (LEVEL 866)

ELEV. 2509 (LEVEL 900)

SHAFT KEY PROFILE

NOT TO SCALE

LEGEND

PRESSURE CELL

PIEZOMETER

NOTES

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH FROM THE
SHAFT COLLAR AT ELEVATION 3409 FT MSL.
2. PRESSURE CELLS LOCATED AT CONCRETE-ROCK INTERFACE.

Figure 3-6
Waste Shaft Key Instrumentation

845' as shown in Figures 3-5 and 3-6. The piezometers are located in the Rustler Formation; those at level 845' are essentially at the Rustler-Salado Formation contact. The piezometer arrays at levels 611' and 717' are located at the water-bearing Magenta and Culebra Dolomite Members, respectively. The piezometers in the Waste Shaft are read remotely.

3.2.2.3 Earth Pressure Cells

Four earth pressure cells were installed in the key section of the Waste Shaft during concrete emplacement from March 23, through April 3, 1984. These were installed as an array at level 866' as shown on Figure 3-6. These instruments measure the horizontal stress between the concrete key and the Salado Formation as the creep effects load the key structure. All earth pressure cells, with the exception of 31X-WE-00201, remain in working condition.

3.3 Exhaust Shaft

The Exhaust Shaft was excavated from September 22, 1983 through November 29, 1984 and established a dedicated route for exhaust air from the underground facility to the surface through the Exhaust Filter Building. Comprehensive geologic mapping was conducted from July 16, 1984 through January 18, 1985 (Holt and Powers, 1986). The generalized Exhaust shaft stratigraphy is presented in Figure 3-7.

The exhaust shaft is lined with unreinforced concrete from the ground surface to the top of the shaft key at a depth of 844 feet. The liner thickness increases from 10 to 16 inches over that distance. The exhaust shaft key is 63 feet long and 3.5 feet thick.

The diameter below the shaft key is 15 feet and is lined with wire mesh anchored by roofbolts. The shaft terminates at the facility horizon, 2150 feet as there is no shaft sump.

3.3.1 Modifications to Excavation

The Exhaust Shaft was inspected in detail from January 27 through January 30, 1987, following several months of grouting work. Due to increased seepage of brine into the shaft, inspections of brine inflows at the key/salt interface were conducted during February and March of 1987. This shaft is no longer accessible because of the lack of a hoisting system and inspections are performed with a video system.

Figure 3-7

3.3.2 Instrumentation

The Exhaust Shaft was equipped with geomechanical instrumentation in two stages. Earth pressure cells were installed behind the liner key during November 1984 and piezometers and extensometers were installed during November and December 1985. The instrumentation configuration is presented in Figures 3-8 and 3-9.

The geomechanical instrumentation in this shaft is connected to LTC-16, which was installed at the facility level to avoid the damage and accessibility problems encountered in the shaft. Since March 5, 1986, LTC-16 has been connected to the datalogging computer. Instrumentation in this shaft are no longer functioning. Please refer to Geotechnical Field Data and Analysis Reports prior to July 1992 for information on this instrumentation.

3.4 Air Intake Shaft

The Air Intake Shaft was excavated from December 4, 1987 through August 31, 1988 and established a route for surface air to the underground facility. Comprehensive geologic mapping was conducted from September 14, 1988 through November 14, 1989 (Holt and Powers, 1990). The generalized Air Intake Shaft stratigraphy is presented in Figure 3-10.

The Air Intake Shaft was lined with unreinforced concrete from the ground surface to a depth of 903 feet, the bottom of the shaft key. The Air Intake Shaft key is 81 feet long with an inside diameter of 16 feet. The shaft diameter below the shaft key is 20 feet and is unlined to depth of 2,150 feet.

3.4.1 Modifications to Excavation

Grouting of the Air Intake Shaft started in April 1993, is scheduled for completion by December 1993.

3.4.2 Instrumentation

At the present time, the Air Intake Shaft is monitored by Sandia National Laboratories and the data collected are not included in this report.

Figure 3-8

Figure 3-9
Exhaust Shaft Key Instrumentation

EXPLANATION

	SAND AND SANDSTONE
	MUDSTONE AND SILTSTONE
	ANHYDRITE
	ROCKSALT
	DOLOMITE

NOTES:

- 1 ALL ROCKS BELOW SANTA ROSA ARE PERMIAN IN AGE.
- 2 RUSTLER DEPTHS WERE MEASURED FROM SUBCOLLAR (18.8' BELOW TOP OF CEMENT). KEYWAY AND BROW WERE MEASURED FROM TOP OF CEMENT (ELEV. 3410' ABOVE MSL).

Figure 3-10
Generalized Air Intake Shaft Stratigraphy

4.0 Performance of Shaft Stations

4.1 Salt Handling Shaft Station

The Salt Handling Shaft Station, Figure 1-2, was excavated from May 2 to June 3, 1982 by drilling and blasting. The station was trimmed to its final dimensions using a continuous miner. The station area south of the shaft is 90 feet long and 32 to 38 feet wide. The height of the station south of the shaft is 18 feet for a distance of 54 feet and 14 feet for the remaining 36 feet. The station dimensions north of the shaft are approximately 30 feet long, 32 to 35 feet wide and 12 feet high. The shaft extends approximately 140 feet below the facility horizon to accommodate the skip loading equipment and to act as a sump to collect any water that might enter the shaft. A generalized cross section of the station is shown in Figure 4-1.

4.1.1 Modifications to Excavation

Modifications made during this reporting period include the installation of roofbolts. A small number of roofbolts were installed in response to the discovery of several failed bolts in the area. Other modifications include local scaling of roof and ribs to remove "drummy" ground.

4.1.2 Instrumentation

Geomechanical instrumentation was installed in the Salt Handling Shaft station from June 1982 through February 1983, with subsequent reinstallation of extensometers and convergence points as necessary. Figure 4-2 details the instrument locations in the Salt Handling Shaft station before the roof was removed. Most of the instruments were either removed, or readings were suspended prior to the mining of the roof. Figure 4-3 details the instrument locations after the roof was taken down.

4.1.2.1 Extensometers

Currently, two functioning extensometers in the Salt Handling Shaft station are located in the roof at S30, and S65. These extensometers were installed in September 1988, replacing two extensometers mined out during trimming activities.

4.1.2.2 Convergence Points

Currently, five convergence point arrays are monitored at N39, S18, S30, S65, and W12.

Figure 4-2
Salt Handling Shaft Station Instrumentation before Roof Excavation

4.2 Waste Shaft Station

The Waste Shaft station was initially excavated with a continuous miner as a ventilation connection to a six foot diameter exhaust shaft in November 1982. In 1984, the shaft station was enlarged to a height of 15 to 19 feet, and a width of 20 to 30 feet, and is approximately 150 feet long. In 1987, the station was trimmed, and concrete was placed on the floor. In February 1991, a portion of the concrete slab was removed. The portion of the concrete slab removed was approximately 53 feet long, 23 feet wide, and 18 inches thick. A generalized cross section of the station is shown in Figure 4-4.

4.2.1 Modifications to Excavation

Modifications made during this reporting period include pattern bolting roofbolts in the brow due to the discovery of a small number of failed bolts in the area. Other modifications include local scaling of the roof and ribs to remove "drummy" ground. A cable-support ground control system was installed in the eastern brow of the waste shaft.

4.2.2 Instrumentation

Initial instrumentation installed between November 12, and December 2, 1982 was destroyed during trimming activities in June 1984. Instruments were replaced in June 1988 upon completion of trimming activities. Figure 4-5 details the instrument locations in the Waste Shaft Station before enlargement of the station, and Figure 4-6 details the locations after enlargement.

4.2.2.1 Extensometers

Currently, three functioning extensometers in the Waste Shaft Station are located in the roof at W30, E35, and E140. Data are collected remotely from the extensometers at E35 and E140 by LTC 17 located at E140-S1300 intersection. At W30 the extensometer is read manually.

Extensometers, located at E35 and E140, were installed on November 29, 1988, and show a total displacement of 3.5 and 3.3 inches, respectively. Extensometer 51X-GE-00268 was installed on October 24, 1984, and indicates a total displacement of 4.4 inches.

4.2.2.2 Convergence Points

Currently, convergence points are monitored at E30, E90, E140, and W30.

Figure 4-4
Generalized Waste Shaft Station Stratigraphy

Figure 4-5
Waste Shaft Station Instrumentation before Trimming

4-7

NOTES:

1. PREVIOUSLY IDENTIFIED AS THE VENTILATION SHAFT STATION.
2. INITIAL INSTRUMENTATION WAS DESTROYED IN JUNE 1984.

Figure 4-6
Waste Shaft Station Instrumentation after Trimming

4.2.2.3 Rockbolt Load Cells

Six rockbolt load cells were installed in February 1988, after trimming in the station was completed. Monitoring of the six rockbolt load cells continues. Twelve rockbolt load cells were installed in the brow of the waste shaft in March 1992. The rockbolt load cells are used to monitor the load on the roofbolts installed in the brow as part of the cable support system and aid in determining when detensioning of the cables is required.

5.0 Performance of Access Drifts

WIPP access drifts (Figure 1-2) were excavated beginning in October 1982 and completed before this reporting period.

5.1 Modifications to Excavation

Strategic roof bolting was performed in locations throughout the E140 and N1420 drift where ground conditions warranted. In most instances roofbolts, and wire mesh when needed, were installed in areas where potentially unstable roof and ribs were found. A small number of roofbolts were installed to replace the failed bolts in E140 and N1420 drifts. A limited amount of pattern bolting was performed on the roof of the alcoves located at E140-S550.

Localized roof bolting occurred in other areas of the underground, which exhibited potentially unstable roof and ribs, and where roofbolts failed. These areas include N1100 drift, Room H, N150 drift, S1950 drift, W30 drift, S1000 drift, W170 drift, L-2 alcove, and L-3 alcove.

A cable support system was installed in the north and south brows of the E0 overcast. A cable support system was installed in E140 between S1300 and S1600.

Scaling was performed in E140 drift where ground conditions warranted. Local scaling was performed in response to the discovery of "drummy" areas of the roof and ribs. The drummy ground was removed in some areas of the E140 and N1420 drifts instead of installing bolts.

Scaling was performed in other areas throughout the underground. These areas include N1100 drift, S1950 drift, Panel 1, N150 drift, W30 drift, E300 drift, S2180 drift, S1000 drift, E0 overcast, S90 drift, L-2 alcove, and L-3 alcove.

Floor milling occurred throughout the E140 drift where conditions warranted and was mainly performed in the area between S90 and S550. Other areas where floor milling occurred include N1100 drift, E0 drift, S1600 drift, S2180 drift, and S1950 drift.

During this reporting period N250 was excavated from approximately E140 to E300, and E300 was extended from S90 to N250. The width of the drift is approximately 25 feet wide. These drifts were excavated for a new maintenance shop therefore, two-foot bolts and expanded wire mesh were installed to contain minor spalls from the roof and ribs and does not serve as a roof support system.

5.2 Instrumentation

Geotechnical instrumentation was installed beginning in October 1982 closely following excavation.

5.2.1 Extensometers

Two sonic probe extensometers were installed in the roof at E140-S1400 and at S1500 in July 1992. The deepest rod was anchored at 14 feet for 51X-GE-00288 located at S1400 and at 11 feet for 51X-GE-00289 located at S1500. The extensometers were installed in a manner such that Anhydrite "a" and Anhydrite "b" are each straddled by two anchors. This installation technique provides a means of monitoring the separation across the anhydrites.

One sonic probe extensometer was installed at E140-S800 in May 1993. The deepest rod was anchored at 24 feet. In June 1993, one sonic probe extensometer was installed at E140-S900 and at S1100 with the deepest rod anchored at 24 feet. In November 1992, three sonic probe extensometers were installed in the E300 Experimental Operations shop. One extensometer was installed in the roof at the north and south end of the room and one at the midpoint of the room. The deepest rod for all three extensometers was anchored at approximately 14 feet.

In the new E300 maintenance shop, a vibrating wire extensometer was installed at four locations: E300-S45; N120; N170; and N240. The deepest rod for all four extensometers was positioned at 13 to 15 feet into the borehole. These installations occurred in May 1993, a few months after excavation.

5.2.2 Convergence Points

New installations during this reporting period include E140 drift, E300 drift, N1100 drift, N1420 drift, Room L1, Room L2, N250-E220, S1600 drift, W170 drift, and W30 drift. These areas with the exception of those in E300 drift and at N250-E220 contain replacement

convergence points that were destroyed as a result of mine maintenance activities.

5.2.3 Joint Meters

During this reporting period, the four joint meters located at the E0-N150 overcast were removed for the construction of the cable support system. These meters are scheduled for reinstallation in 1994. The four joint meters located at the S1950 overcast continue to operate.

5.3 Excavation Performance

This section describes the in situ geomechanical performance of the access drifts, interprets underground conditions, and highlights any significant events. Generally, the openings are performing satisfactorily; as the openings age, the effects of deterioration increase. An additional assessment, using the results from the Excavation Effects inspections and roofbolt failure observations, is discussed in Section 9.0.

5.4 Analysis of Convergence Data

Measurements of excavation closure are evaluated as a primary means of identifying areas where conditions may be deteriorating. Closure measurements are made throughout the facility, approximately every two months, and are used in conjunction with other observations to assess the geomechanical performance of the excavations. Points that significantly vary from a closure model are monitored more closely to determine the cause of the variance.

Closure rates are determined by using radial convergence points, which measure the reduction in distance between opposing surfaces of the excavations over time. Radial convergence points are: accurate; easy to install and read; and provide data that are analyzed with simple engineering techniques. Closure rates indicate the trend of how an excavation is performing; rates that are steady or slow down with time generally indicate stable excavations whereas increasing closure rates, or rates that are consistently higher than anticipated, may indicate potential instability. Previously reported results (DOE, 1990), indicate that closure rates generally decline with time and show cyclic variations that can be attributed to seasonal temperature changes.

Closure rates are plotted over time on a routine basis. In addition, rates are compared to

predicted values. The predictions are based on a statistical evaluation of selected data from openings of various sizes and ages that provide an empirical relationship between closure rates, room dimensions, and the age of the excavation. The relationship is updated annually as additional data become available. This approach provides an equation for closure rate as a transient function of time and opening dimensions (Table 5-1a). Predicted values are assessed at an upper bound, based on a 95 percent prediction limit from the statistical analysis. Parameters A, b, c, and d and the 95 percent prediction limit are determined using a nonlinear regression method (Statgraphics, Version 4.0). A similar analysis was performed to obtain a predictive equation for closure rates at intersections (Table 5-1b).

Measured closure rates from July 1, 1992, to June 30, 1993, from locations throughout the underground are compared to the predicted values (Table 5-2a and 5-2b). Actual closure rates are generally in agreement with predicted rates. At locations where the actual value exceeds the predicted value, additional studies were performed and explanations for the differences are provided in the table. If the cause of high closure rates cannot be adequately explained (i.e., recent mining nearby or instrument malfunction⁸), the location is monitored more frequently and further field studies may be initiated.

The results of these analyses indicate that the underground is performing within the bounds of the empirical analyses with the exception of the following areas:

- Parts of E140 drift. This drift is the main haulage route to the waste storage area and remedial measures have been taken to increase stability in the affected areas
- SPDV Room 2

Convergence rates in SPDV Room 2 are closely monitored. This room has been barricaded since 1989 due to deteriorating conditions. For further information see DOE/WIPP 93-033.

Table 5-1a
Analyses of Underground Closure Rates
 (Convergence data through June 30, 1993)

Closure	Parameter:				
	A	b	c	d	R ²
Roof to Floor	0.0026	1.0063	1.1896	-0.2170	0.875
Wall to Wall	0.0102	0.5765	1.0786	-0.2698	0.798

Notes:

1. Parameters A, b, c, d, are determined using nonlinear regression techniques (STATGRAPHICS Version 4.0).
2. Parameters used in the following relationship:

$$C(t) = A * w^b * h^c * t^d * (365/200)$$

Where: C(t) = closure rate (inches/year)
 w = room width (feet)
 h = room height (feet)
 t = age of excavation (years)

3. R² is the coefficient of determination.

Table 5-1b
Analyses of Underground Closure Rates at Intersections
 (Convergence data through June 30, 1993)

Closure	Parameter:				
	A	b	c	d	R ²
Roof to Floor	0.0043	0.7370	0.5354	-0.2436	0.880

Notes:

1. Parameters A, b, c, d, are determined using nonlinear regression techniques (STATGRAPHICS Version 4.0).
2. Parameters used in the following relationship:

$$C(t) = A * a^b * h^c * t^d * (365/200)$$

Where: C(t) = closure rate (inches/year)
 a = intersection area (feet²)
 h = room height (feet)
 t = age of excavation (days)

3. R² is the coefficient of determination.

Table 5-2a
Mid-Room Roof to Floor Closure Rates

Field Tag	Location	Date of Excavation	Closure Rate 1988-89 (in/yr)	Closure Rate 1989-90 (in/yr)	Closure Rate 1990-91 (in/yr)	Closure Rate 1991-92 (in/yr)	Closure Rate 1992-93 (in/yr)	Upper Bound of Predicted Closure 1992-93 (in/yr)	Comments
W170-S1150 RC:A-E	W170 drift-S1150	21-Aug-84	1.03	0.79	0.79	0.78	0.64	1.26	
W170-S1000 RC:A-C	W170 drift-S1000								
	intersection	19-Aug-84	1.24	0.88	0.81	0.80	0.64	1.29	
W170-S700 RC:A-C	W170-S700 drifts								
	intersection	14-Aug-84	1.03	0.74	0.72	0.71	0.63	1.28	
W170-S5 RC:A-C	W170 drift-S5	28-Jul-87	0.87	0.58	0.64	0.62	0.50	1.27	
W30-S120 RC:A-C	W30 drift-S120	29-Jul-87	1.23	0.97	0.92	0.91	0.96	1.48	
W30-S1000 RC:2:A-C	W30-S1000 drifts								
	intersection	21-Aug-84	2.66	1.81	1.30	1.28	1.09	1.85	
W30-S850 RC:2:A-E	W30 drift-S850	15-Aug-84	1.06	0.61	0.78	0.68	0.67	1.30	
W30-S700 RC:A-C	W30-S700 drifts								
	intersection	08-Aug-84	1.98	0.74	1.08	1.04	0.92	1.91	
W30-S500 RC:A-C	W30 drift-S500	08-Aug-84	1.29	0.78	0.89	0.83	0.73	1.62	
W30-S250 RC:3:A-C	W30 drift-S250	28-Sep-84	1.32	0.82	0.87	0.96	1.01	1.61	
E0-N626 RC:3:A-C	E0 drift-N626	20-Feb-85	1.61	2.81	1.96	1.98	2.02	1.80	Nearby excavation in E140 drift.
E0-N940 RC:3:A-C	E0 drift-N940	22-Feb-85	1.75	2.53	1.95	2.03	1.88	1.74	Rate Higher than predicted, although trending downward
E0-N1110 RC:3:A-C	E0-N1100 drifts								
	intersection	04-Mar-85	1.60	1.51	1.40	1.38	1.24	1.65	
E0-N1266 RC:3:A-C	E0 drift-N1266	16-Jan-85	1.66	1.82	1.80	1.79	1.70	1.80	
E140-S460 RC:3:A-C	E140 drift-S460	15-Jun-84	1.56	2.02	2.07	2.02	1.99	2.56	
E140-S550 RC:3:A-C	E140 drift-S550	01-Mar-88	2.01	1.62	1.61	1.53	1.39	2.27	
E140-S850 RC:5:A-C	E140 drift-S850	07-Jun-84	1.50	1.78	1.69	1.60	1.45	2.36	
E140-S1000 RC:A-C	E140-S1000 drifts								
	intersection	01-Mar-88	1.89	1.62	1.36	1.35	1.20	2.06	
E140-S1150 RC:A-C	E140 drift-S1150	14-Jun-84	1.62						
E140-S1150 RC:2:A-C	E140 drift-S1150	28-Dec-87	2.55	2.20	2.06	2.10	2.24	2.37	
E140-S1246 RC:2:A-C	E140 drift-S1246	11-Jun-84							
E140-S1246 RC:3:A-C	E140 drift-S1246	01-Mar-88	2.86	2.37	2.01	1.84	1.63	2.23	
E140-S1300 RC:A-C	E140-S1300 drifts								
	intersection	01-Mar-88	2.29	1.83	1.55	1.49	1.52	1.95	
E140-S1450 RC:4:A-E	E140 drift-S1450	18-Jun-84		2.72	2.61	2.33	2.07	2.29	
E140-S1600 RC:2:A-C	E140-S1600 drifts								
	intersection	01-Mar-88		1.97	1.71	1.66	1.53	2.13	
E140-S1879 RC:2:A-C	E140 drift-S1879	06-Jan-88	3.16	2.69	2.79	2.92	2.19	2.30	
E140-S1950 RC:2:A-C	E140-S1950 drifts								
	intersection	01-Mar-88		2.08	1.72	1.66	2.10	2.03	Rate higher than predicted.
E140-S2350 RC:A-C	E140 drift-S2350	17-Jan-83	1.13						Area not accessible.
E140-S2625 RC:A-C	E140 drift-S2625	17-Jan-83	0.94						Area not accessible.

Table 5-2a (Continued)
Mid-Room Roof to Floor Closure Rates

Field Tag	Location	Date of Excavation	Closure	Closure	Closure	Closure	Closure	Upper	Comments
			Rate 1988-89 (in/yr)	Rate 1989-90 (in/yr)	Rate 1990-91 (in/yr)	Rate 1991-92 (in/yr)	Rate 1992-93 (in/yr)	Bound of Predicted Closure 1992-93 (in/yr)	
E140-S2950 RC:A-C	E140 drift-S2950	29-Jan-83	0.88						Area not accessible.
E140-S3250 RC:A-C	E140 drift-S3250	03-Feb-83	0.85						Area not accessible
E140-S3614 TC:A-C	E140 drift-S3614	29-Jan-83	0.82						Area not accessible TC = temporary convergence point
E140-S3639 TC:A-C	E140 drift-S3639	29-Jan-83	0.71						Area not accessible
E140-S3664 RC:A-C	E140 drift-S3664	12-Feb-83	0.37						Area not accessible
E140-N5 RC:2:A-C	E140 drift-N5	24-May-84	1.33	1.00	1.11	1.28	1.37	1.93	
E140-N240 RC:2:A-C	E140 drift-N240	22-Feb-83	0.97	0.28					Data no longer collected in this area.
E140-N626 RC:2:A-C	E140 drift-N626	24-Feb-83	0.92	0.20		3.20	2.63	2.26	Nearby excavation
E140-N1266 RC:A-C	E140 drift-N1266	28-Feb-83	0.97	0.67	3.10	2.71	2.39	2.36	Rate higher than predicted, although trending downward
E300-S1150 RC:3:A-E	E300 drift-S1150	26-Jul-84	0.80	0.66	0.60	0.56	0.46	1.39	
E300-S1000 RC:A-C	E300 drift-S1000	25-Jul-84	0.89	0.62	0.64	0.60	0.50	1.30	
E300-S850 RC:A-E	E300 drift-S850	25-Jul-84	0.74	0.44	0.52	0.49	0.39	1.34	
E300-S700 RC:A-C	E300 S700 drifts intersection	24-Jul-84	0.92	0.65	0.69	0.66	0.55	1.29	
S90-W100 RC:A-C	S90 drift-W100	28-Jul-87	0.85	0.54	0.58	0.56	0.45	1.34	
S90-W400 RC:A-C	S90 drift-W400	03-Dec-87	1.35	1.02	0.76	0.64	0.53	1.50	
N140-E90 RC:A-C	N150 drift-E90	29-Jul-87	0.77	0.56	0.68	0.76	0.79	1.26	
N1110-E80 RC:3:A-C	N1100 drift-E80	12-Jan-84	0.62	1.06	0.96	0.90	0.89	1.14	
TR2-N1110 RC:2:A-C	N1100 drift-Test Room 2 intersection	19-Apr-84	1.81	1.61	1.43	1.29	1.16	1.87	
N1110-W783 RC:2:A-C	N1100 drift-W783	04-Feb-86	0.84	0.86	0.78	0.74	0.66	1.27	
N1110-W951 RC:2:A-C	N1100 drift-W951	04-Feb-86	0.71	0.74	0.62	0.61	0.57	1.28	
N1110-W1159 RC:2:A-C	N1100 drift-W1159	04-Feb-86	0.83	0.85	0.73	0.71	0.62	1.24	
N1110-W1347 RC:2:A-C	N1100 drift-W1347	04-Feb-86	0.79	0.84	0.74	0.80	0.64	1.30	
N1420-W258 RC:A-E	N1420 drift-W258	07-Apr-84	1.17	1.29	1.19	1.12	1.09	1.48	
N1420-W365 RC:A-C	N1420 drift-Test Room 2 intersection	07-Apr-84	2.37	2.51	2.30	2.18	2.61	2.35	Rates are accelerating in Test Room 2.
N1420-W391 RC:A-E	N1420 drift-W391	07-Apr-84	1.31	1.38	1.24	1.17	1.13	1.46	
N1455-W365 RC:A-E	Room L2	30-Apr-84	1.79	1.91	1.69	1.63	1.48	2.20	
E520-S1802 RC:6:A-C	Panel 1 Room 1	30-May-86	4.44	3.47	3.82	3.21	2.76	2.76	
E660-S1775 RC:5:A-C	Panel 1 Room 2	23-Jan-87	4.64	2.95	2.76	2.48	2.17	2.74	
E790-S1775 RC:3:A-C	Panel 1 Room 3	19-Feb-87	4.68	3.18	2.56	2.42	2.22	2.67	
E920-S1775 RC:5:A-F	Panel 1 Room 4	03-Feb-88	4.54	3.89	2.45	2.35	2.32	2.72	
E1050-S1775 RC:4:A-F	Panel 1 Room 5	12-Feb-88	4.00	2.60	2.17	2.12	2.07	2.64	
E1190-S1775 RC:4:A-F	Panel 1 Room 6	26-Feb-88	4.74	3.25	2.61	2.48	2.41	2.65	
E1320-S1775 RC:2:A-F	Panel 1 Room 7	10-Mar-88	4.53	3.12	2.54	2.48	2.31	2.64	

Note: Fieldtag represents most recent installation.

Table 5-2b
Mid-Room Wall to Wall Closure Rates

Field Tag	Location	Date of Excavation	Closure Rate 1988-89 (in/yr)	Closure Rate 1989-90 (in/yr)	Closure Rate 1990-91 (in/yr)	Closure Rate 1991-92 (in/yr)	Closure Rate 1992-93 (in/yr)	Upper Bound of Predicted Closure 1992-1993 (in/yr)	Comments
W170-S1150 RC:C-G	W170 drift-S1150	21-Aug-84	1.11	0.81	0.87	0.79	0.70	1.07	
W170-S5 RC:B-D	W170 drift-S5	28-Jul-87	0.96	0.66	0.72	0.65	0.56	1.07	
W30-S850 RC:C-G	W30 drift-S850	15-Aug-84	1.07	0.73	0.83	0.86	0.72	1.08	
W30-S500 RC:B-D	W30 drift-S500	08-Aug-84	1.29	0.82	0.88	0.78	0.73	1.23	
W30-S250 RC:3:B-D	W30 drift-S250	28-Sep-84	1.22			1.00	0.76	1.22	
E0-N1266 RC:4:B-D	E0 drift-N1266	16-Jan-85	1.14	1.07	1.16		1.00	1.31	
E140-S460 RC:2:B-D	E140 drift-S460	09-Mar-88	1.56	1.22	1.22	1.20	1.14	1.70	
E140-S550 RC:4:B-D	E140 drift-S550	16-Mar-88	1.60	1.28	1.25	1.17	1.03	1.52	
E140-S850 RC:3:B-D	E140 drift-S850	07-Jun-84	1.50	1.08	1.02	0.94	0.83	1.59	
E140-S1150 RC:2:B-D	E140 drift-S1150	14-Jun-84	0.62	1.27	1.14	1.07	1.06	1.62	
E140-S1246 RC:3:B-D	E140 drift-S1246	01-Mar-88	1.25	1.13	1.54	1.06	0.95	1.51	
E140-S1450 RC:2:B-D	E140 drift-S1450	18-Jun-84	1.77	0.97	0.96	0.90	0.84	2.36	
E140-S1879 RC:2:B-D	E140 drift-S1879	06-Jan-88	1.44	1.30	1.60	1.29	1.14	1.58	
E140-S2350 RC:B-D	E140 drift-S2350	17-Jan-83	0.86						Not accessible.
E140-S2625 RC:B-D	E140 drift-S2625	17-Jan-83	0.70						Not accessible.
E140-S2950 RC:B-D	E140 drift-S2950	29-Jan-83	0.74						Not accessible.
E140-S3250 RC:B-D	E140 drift-S3250	03-Feb-83	0.57						Not accessible.
E140-S3614 TC:B-D	E10 drift-S3614	29-Jan-83	0.70						Not accessible. TC = temp. convergence point
E140-S3639 TC:B-D	E140 drift-S3639	29-Jan-83	0.53						Not accessible.
E140-S3664 RC:B-D	E140 drift-S3664	29-Jan-83	0.28						Not accessible.
E140-N5 RC:2:B-D	E140 drift-N5	24-May-84	1.03	0.72	0.85	1.00	1.13	1.31	
E140-N626 RC:B-D	E140 drift-N626	24-Feb-83	0.81	0.09		2.14	1.64	1.52	Nearby excavation..
E140-N1266 RC:3:B-D	E140 drift-N1266	28-Feb-83	0.67	0.73	1.87	1.47			
E300-S1150 RC:C-G	E300 drift-S1150	26-Jul-84	0.89	0.73	0.71	0.68	0.54	1.08	
E300-S850 RC:C-G	E300 drift-S850	25-Jul-84	0.82	0.54	0.60	0.58	0.42	1.09	
S90-W100 RC:B-D	S90 drift-W100	28-Jul-87	0.55	0.58	1.11	0.55	0.47	1.10	
S90-W400 RC:B-D	S90 drift-W400	03-Dec-87	1.32	1.03	0.85	0.63	0.50	1.28	
N140-E90 RC:B-D	N150 drift-E90	29-Jul-87	0.55	0.68	1.08	0.79	0.85	1.08	
N140-W50 RC:B-D	N150 drift-W50	31-Jul-87	1.06	1.01	1.59	1.03	0.83	1.56	
N1110-E80 RC:3:B-D	N1100 drift-E80	12-Jan-84	0.60	1.06	0.95	0.81			Not read this period.
N1110-W783 RC:2:B-D	N1100 drift-W783	04-Feb-86	0.58	0.67	0.58	0.55	0.47	1.01	
N1110-W951 RC:2:B-D	N1100 drift-W951	04-Feb-86	0.53	0.58	0.49	0.47	0.41	1.02	

Table 5-2b (Continued)
Mid-Room Wall to Wall Closure Rates

Field Tag	Location	Date of Excavation	Closure Rate 1988-89 (in/yr)	Closure Rate 1989-90 (in/yr)	Closure Rate 1990-91 (in/yr)	Closure Rate 1991-92 (in/yr)	Closure Rate 1992-93 (in/yr)	Upper Bound of Predicted Closure 1992-93 (in/yr)	Comments
N1110-W1159 RC-2:B-D	N1100 drift-W1159	04-Feb-86	0.60	0.61	0.52	0.50	0.43	1.03	
N1110-W1347 RC-2:B-D	N1100 drift-W1347	04-Feb-86	0.58	0.63	0.54	0.51	0.46	1.02	
N1420-W258 RC-4:C-G	N1420 drift-W258	07-Apr-84	1.17	1.45	1.37	0.69	0.86	1.90	
N1420-W391 RC-3:C-G	N1420 drift-W391	07-Apr-84	1.55		1.32	0.76	0.95	1.26	
N1455-W232 RC:C-G	Room L1	24-Apr-84							Not read this period, blocked by equipment.
N1455-W365 RC-3:C-G	Room L2	30-Apr-84	1.28	1.41	1.27	1.22	1.17	1.62	
E520-S1802 RC-3:C-G	Panel 1 Room 1,	30-May-86	2.56	1.89	1.78	1.46	1.26	1.70	
E660-S1775 RC-5:B-D	Panel 1 Room 2	23-Jan-87	2.94	1.93	1.55	1.51	1.14	1.74	
E790-S1775 RC-5:B-D	Panel 1 Room 3	19-Feb-87	3.27	2.13	1.65		1.35	1.74	
E920-S1775 RC-4:D-G	Panel 1 Room 4	03-Feb-88	3.32	1.99	1.57	1.50	1.29	1.81	
E1050-S1775 RC-4:D-G	Panel 1 Room 5	12-Feb-88	3.09	1.93	1.50	1.37	1.28	1.81	
E1190-S1775 RC-3:D-G	Panel 1 Room 6	26-Feb-88	2.88	1.97	1.55	1.35	1.17	1.70	
E1320-S1775 RC-5:D-G	Panel 1 Room 7	10-Mar-88	2.94	1.87	1.43	1.39	1.16	1.82	

Note: Fieldtag represents most recent installation.

6.0 Performance of SPDV Rooms and Non Radioactive Experimental Area

The Site and Preliminary Design Validation (SPDV) Rooms, located in the northwest section of the underground facility, were excavated as a four-room panel in early 1983 (Figure 1-2). The rooms were equipped with geomechanical instrumentation almost immediately after excavation. The SPDV Rooms were mined to the same specifications as the repository storage rooms (13-feet high, 33-feet wide, 300-feet long, 100-foot pillars) to validate the storage room design.

The Design Criteria for the storage rooms required total vertical and horizontal closure to remain below certain limits. However, closure in the SPDV Rooms was found to be higher than anticipated values that were based on laboratory test results.

After design validation was considered complete, geomechanical monitoring of the SPDV Rooms was continued, to verify modeling that simulates the long-term behavior of the storage rooms. While the behavior of the SPDV Rooms is relevant to the storage rooms, it must be remembered that variability is inherent in natural materials such as salt. Although the rooms have behaved differently, the SPDV Rooms still provide a good corollary to the waste storage rooms.

6.1 Modifications to Excavations

Fly ash blocks were installed in the north and south ends of SPDV Rooms 1, 2, and 3 in June 1993.

6.2 Instrumentation

Geotechnical instrumentation was installed in the SPDV rooms in March and April 1983. Instrument locations for SPDV Rooms 2 and 4 and the waste experimental area are shown in Figures 6-1 and 6-2, respectively.

6.2.1 Extensometers

Currently, three extensometers have been operational at the midpoint of SPDV Room 4 since April 1983. Extensometer 51X-GE-00206, located in the east rib, has a total displacement of

Figure 6-1
SPDV Room 2 Convergence Meter Locations

Figure 6-2
SPDV Room 4 Instrumentation

7.7 inches. Extensometer 51X-GE-00207, located in the roof, has a total displacement of 10.5 inches. Extensometer 51X-GE-00208, located in the west rib, has a total displacement of 6.0 inches.

Extensometer 51X-GE-00209, located in the floor of SPDV Room 4, was last read in February 1992 because the floor was trimmed and the extensometer was not reinstalled.

6.2.2 Convergence Points

The convergence points located in SPDV Rooms 1, 2, and 3 remain inaccessible. All convergence points in SPDV Room 4 continue to be read regularly. Arrays of convergence points in SPDV Room 4 are located at the north end of the room, at the midpoint, and at the south end of the room. The arrays located at the north and south of the room were installed in April 1989. The vertical closure rate at room centerline for the north and south end of the room are 2.2 inches per year (in./yr) and 2.0 in./yr, respectively. Vertical closure rate at midpoint of the room, centerline is 2.7 in./yr. The midpoint array was installed in May 1983 and has been read continuously since installation.

6.2.3 Convergence Meters

The convergence meter 51X-GE-00201, located in SPDV Room 2, has reached its maximum length of travel and is no longer read. Remote monitoring of all twelve wire convergence meters in SPDV Room 2 continues.

6.3 Excavation Performance

Only SPDV Room 4 is currently open and in use. Poor ground conditions caused the other rooms to be barricaded. The rooms were barricaded rather than remediated so that the long term performance of unsupported, unmaintained rooms could be studied. Allowing one or two excavations to safely deform to the point of roof failure gives ground control engineers a reference to compare potential instability in other drifts. It should be noted, however, that all the rooms could have been and can be restored to safe operating conditions, if desired, using common mining practices. The status of the SPDV Rooms are summarized below:

SPDV 1: Closed to all but geotechnical monitoring activities in May 1989. Closed to all activities in November 1989. A substantial roof fall occurred in February 1991. This was initially predicted in October 1989 and was confidently predicted in November 1990.

- SPDV 2:** Closed in November 1989. Monitored with remote instrumentation. No falls of ground have occurred. A substantial roof fall is predicted to occur between October 1993 and April of 1995.
- SPDV 3:** Closed in June 1990. Due to inaccessibility and the absence of remotely read instruments in the room, no life estimate is available.
- SPDV 4:** Open and in use. Receives routine maintenance. Current life is long, but indefinite.

6.3.1 SPDV Room 1 Roof Fall

The first signs of instability in SPDV Room 1, in the form of high, asymmetric convergence rates, were recognized in early 1989. Instrumentation in the room was then upgraded and observation boreholes were added. The additional boreholes confirmed that a large slab potentially over a hundred feet long had developed in the roof. At that time, drilling was suspended, and the room was closed to routine activities. Thereafter, only geotechnical crews were allowed to enter the room to install remote reading instrumentation and to thoroughly map fractures. When this was completed, the room was permanently barricaded in November 1989, fifteen months before the roof fell. The long lead time between identification of the problem and the actual roof fall is typical in salt. The creep process by which salt deforms does not allow large amounts of energy to build up in the rock mass. Unless pressurized gas or brine are present, the failure of salt is slow.

Analyses of the instrument data and fracture maps from SPDV Room 1 have allowed WIPP engineers to develop a rational interpretation of the mechanisms that led to failure in this room. To summarize:

- The expansion of the pillars surrounding the excavation impart horizontal loads on the relatively thin beam of halite in the roof.
- The clay seam in the roof is too weak to transmit this horizontal force to the strata above.
- The horizontal load causes fractures to develop in the roof beam originating near the corners and terminating at the clay seam at the center of the room.
- The orientation and location of the fractures are controlled in part by zones of weakness located at the corners of the excavation and by the orientation of the stresses in the roof beam.

- Without ground support the fractures may lengthen and eventually a roof fall may occur.

The deformation patterns and the type of roof fall seen in SPDV Room 1 are common in mining bedded salt and potash. The mining industry has developed proven methods to control such occurrences. Several of these methods are being used at the WIPP which may minimize fracturing that may lead to roof falls.

The roof fall in SPDV Room 1 was essentially a continuation of the Design Validation process. The Design Validation Final Report recommended that the SPDV Rooms not be supported or otherwise altered so that their deformation could be further studied. Rather than remediate the unstable roof of SPDV Room 1, personnel and equipment were removed from the room as soon as there was a remote possibility of a roof fall and remotely monitored until failure.

Using the results from SPDV Room 1 for excavation and ground support design is conservative for several reasons. The life of SPDV Room 1 (time from excavation to roof fall) was unusually short. The other SPDV Rooms have remained intact about 30 percent (about 2.5 years) longer without a roof fall. Roof fracturing was worse in SPDV Room 1 than in any other similar sized opening. SPDV Room 1 had wire mesh installed with two foot roofbolts that contained minor spalls from the roof. Other excavations for which SPDV Room 1 is used as a design base have ten-foot roofbolts that serve as a ground control system.

The ground support system for Room 1, Panel 1 used SPDV Room 1 as a "worst case" design basis. SPDV Room 1 serves as a worst case because it was unsupported and allowed to reach failure. The life of a room can be extended through ground control systems and routine maintenance when the interpretation of geomechanical monitoring data may indicate deterioration.

6.3.2 SPDV Room 2 Stability and Roof Fall Prediction

SPDV Room 2 has been barricaded since late 1989. Fly ash block walls were installed at both ends of the room last year, allowing limited visual inspection of SPDV Room 2. The geomechanical information currently being collected from SPDV Room 2 is from twelve wire

convergence meters that measure roof to floor closure at various locations in the room (Figure 6-1). Convergence rates have increased over the last year for ten of the twelve instruments, with a sixteen percent increase in the south end of the room. At the time of writing, the highest closure rate was over seven inches per year at the location near the west rib about 75 feet from the N1100 drift. Fracturing in the roof of SPDV Room 2 has not been surveyed since 1989. The roof fracturing was well developed at that time.

Identification of the deformation mechanisms and the geomechanical instrument responses that led to the SPDV Room 1 roof fall formed the bases for a prediction of the time of a roof fall in SPDV Room 2. This is thoroughly documented in DOE/WIPP 93-033, Current Bases for Roof Fall Prediction at WIPP and a Preliminary Prediction for SPDV Room 2 (DOE, 1993a) which estimates that a roof fall in SPDV Room 2 will occur between October 1993 and April 1995. This prediction is continually updated based on the convergence data.

6.3.3 SPDV Room 3

SPDV Room 3 was barricaded in June of 1990 and ten-foot roofbolts were installed in the north half of the room in November 1990. Fly ash block walls were installed at both ends of the room in 1993, allowing only limited visual inspection of SPDV Room 3. Instruments installed in SPDV Room 3 have not functioned for several years. At the time the room was barricaded, the condition of the roof was comparable to that of SPDV Room 2.

6.3.4 SPDV Room 4

SPDV Room 4 is the only SPDV Room still accessible. It is primarily used as a warehouse and for access to the N1420 drift. The roof of the room is pattern bolted with ten foot mechanical roofbolts. Geomechanical conditions in SPDV Room 4 have always been better than in the other SPDV Rooms. Convergence and borehole extensometer data are collected from SPDV Room 4 and are supplemented with visual observations. Convergence rates are relatively low, less than three inches per year. Roof displacement rates as measured by the extensometer are stable. Roof fracturing in the north half of the room is beginning to form a wedge-shaped pattern. The convergence at the north array is slightly asymmetric across the width of the room, with the east side moving about twenty percent faster than the west side. These are precursors indicative of roof instability or floor lift but are minimal and not cause for concern.

7.0 Performance of Waste Storage Area

Excavation of the waste storage area began in May 1986 with the mining of entries to Panel 1. Initially, the storage rooms and drifts were developed as pilot drifts that were later excavated to 13 feet high, 33 feet wide, and 300 feet long. Room 1 was excavated to near full dimensions in August 1986, and pilot drifts for storage rooms 2 and 3 were excavated in January and February of 1987. Rooms 4 through 7 were completed between March and May of 1988.

In 1991, a supplementary roof support system was designed and installed in Room 1, in order to facilitate a bin-scale test program. At that time, the existing geotechnical monitoring system in the room was upgraded to meet the needs of evaluating the performance of both Room 1 and the support system. A detailed description of the installation is presented in the Waste Isolation Pilot Plant Supplementary Roof Support System Underground Storage Area Room 1, Panel 1 (DOE, 1991). Detailed analyses of the system performance, maintenance activities, and procedure development are presented in performance summaries (DOE, 1992; DOE, 1993b; DOE, 1993c).

7.1 Modifications to Excavation

During this reporting period additional roofbolts were installed in Room 6, Panel 1, and scaling was performed at various locations throughout the panel. No new excavations were mined in the Waste Storage Area during the reporting period.

7.2 Instrumentation

Installation of convergence points immediately followed the completion of each mining pass. Multi-point borehole extensometers were installed after completion of the final room trimming and drilling of the boreholes.

7.2.1 Extensometers

Three roof extensometers were installed in the panel during this reporting period for a total of twenty-two extensometers in the panel rooms. Due to the amount of operational activity in Room 1, remote data acquisition capabilities were terminated on several occasions and manual data collection initiated. Sudden increases and decreases, indicated on the raw plots,

are a result of a change in data collection methods.

The three sonic probe extensometers installed in the roof of Room 7 consisted of four rods for each extensometer. The extensometers were installed such that they straddle Anhydrites "a" and "b", with the deepest anchor at 14 to 15 feet into the roof.

7.2.2 Convergence Points

The original convergence points in Room 7, were destroyed as a result of scaling activities. The convergence points were reinstalled in April 1993.

7.2.3 Convergence Meters

Monitoring of four convergence meters in Room 6 continued during this reporting period. The convergence meters were placed at the midpoints of Room 6 to monitor horizontal and vertical closure of the room.

7.2.4 Rockbolt Load Cells

The 286 rockbolt load cells in the Room 1 yielding roof support system are monitored on a weekly basis and aid in determining when detensioning of the bolts is required. The bolts were detensioned quarterly based on the load indicated by the rockbolt load cells. By detensioning, the loads were reduced from approximately 20 kips down to 5 kips.

7.3 Excavation Performance

Convergence points were installed at selected locations immediately following excavation in order to collect early closure data. Tables 7-1a and 7-1b compare the closure rate for the Panel 1 storage rooms and the SPDV rooms. Although the history of the Panel 1 rooms is shorter than the SPDV rooms, a similar pattern of closure is emerging. The vertical closure rates in Room 1, Panel 1 have shown a slight decrease from the last reporting period. Room 1, Panel 1, data will continue to be compared with data from the SPDV rooms in order to determine the effect of the supplemental roof support system on the life of the room. Roof to floor convergence data indicate that the closure in the waste storage areas is comparable to that of the SPDV rooms at a similar stage of development.

Table 7-1a
Closure Rates by Time Since Excavation
Vertical Convergence Data (inches/year)

ROOM	DATE OF EXCAVATION AT INSTRUMENT	EXCAVATION COMPLETED TO FINAL DIMENSIONS	YEAR							
			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
PANEL 1:										
ROOM 1	June 1986	August 1986	4.13	4.26	4.60	3.24	3.56	3.08	2.76	
ROOM 2	January 1987	March 1988	3.02	6.71	3.33	2.91	2.60	2.32		
ROOM 3	February 1987	March 1988	1.60	9.85	3.34	2.71	2.46	2.32		
ROOM 4	February 1988	March 1988	8.33	3.14	2.56	2.37	2.36			
ROOM 5	February 1988	March 1988	9.19	2.76	2.28	2.17	2.10			
ROOM 6	February 1988	May 1988	8.36	3.41	2.76	2.49	2.44			
ROOM 7	March 1988	March 1988	9.26	3.22	2.70	2.51	2.41			
SPDV:										
ROOM 1	April 1983	April 1983	6.79	3.75	2.93	2.88	2.85	3.32	4.46	12.40
ROOM 2	March 1983	March 1983	7.10	3.18	2.39	2.19	2.14	2.33	2.74	2.87
ROOM 3	March 1983	March 1983	7.89	3.75	2.73					
ROOM 4	April 1983	April 1983	5.40	3.18	2.65	2.33	2.13	2.30	2.45	2.31

Notes: Year is determined from date of excavation at instrument.

Table 7-1b
Closure Rates by Time Since Excavation
Horizontal Convergence Data (inches/year)

ROOM	DATE OF EXCAVATION AT INSTRUMENT	EXCAVATION COMPLETED TO FINAL DIMENSIONS	YEAR							
			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
PANEL 1:										
ROOM 1	June 1986	August 1986	4.24	3.00	2.72	1.80	1.78	1.52	1.30	
ROOM 2	January 1987	March 1988	1.67	5.29	2.03	1.64	1.43	1.26		
ROOM 3	February 1987	March 1988	1.63	8.14	2.26	1.76	1.60	1.41		
ROOM 4	February 1988	March 1988	6.53	2.16	1.67	1.55	1.34			
ROOM 5	February 1988	March 1988	6.92	2.10	1.66	1.50	1.36			
ROOM 6	February 1988	May 1988	7.37	2.09	1.64	1.39	1.28			
ROOM 7	March 1988	March 1988	6.53	1.93	1.50	1.37	1.16			
SPDV:										
ROOM 1	April 1983	April 1983	5.56	2.47	1.95	1.79	1.56	1.89		
ROOM 2	March 1983	March 1983	5.06	2.16	1.63	1.52	1.42	1.55	(1.85)	
ROOM 3	March 1983	March 1983	6.46	2.28	1.75	1.50	2.08	1.77	1.77	
ROOM 4	April 1983	April 1983	4.55	1.79	1.53	1.29	1.17	1.31	1.36	1.28

Notes: Year is determined from date of excavation at instrument.

() Estimate based on less than one full year of data.

The supplementary roof support system continues to function in accordance with the design, showing no signs of instability in either the support system itself or the strata in which the support system is located. In Room 1, Panel 1, the roof expansion rate averages 0.6 inches per year, as of May 27, 1993, compared to the rate of 1.5 inches per year assumed in the original design specifications (DOE, 1993c). The projected useful life of the room from May of 1993 is 20 years. This is based on minimum clearance of the waste handling forklift, maximum floor lift rates, and maximum bolt anchorage horizon displacement rates (DOE, 1993c).

8.0 Excavation Effects Program

Excavation effects, which are the structural responses of the rock mass to excavations, have been observed and monitored since mining of the underground facility began at the WIPP. A historical summary of excavation effects activities are presented in Table 8-1. During this reporting period, observations of excavation effects have included:

- Observations of subsurface fractures in boreholes
- Mapping of fractures on excavation surfaces
- Observations of rockbolt failures.

These observations detect, quantify, and assist in the interpretation of fractures and bed separations that result from the underground excavations. The size and orientation of fracture apertures or of bedding plane separations are recorded as the value at the excavation surface in which such features are located. When possible, indirect measurement or visual estimates are made of the distance that a fracture or separation extends into the rock.

8.1 Borehole Fracture Observations

Systematic borehole observations were started in mid-1986 to study fractures and separations in the roof and the floor of the repository. This program consists of an annual inspection of boreholes that are arranged in arrays located throughout the underground as shown in Figure 8-1. A typical array is shown in Figure 8-2. Variation in the field data resulting from interpretation by individual inspectors must be taken into consideration when evaluating the results presented here. Graphical representation of the arrays is available upon request.

8.1.1 Interpretation of Fracture Observations

The results of the 1993 survey are compared with the results of previous surveys in Table 8-2. The fractures in roof and floor boreholes are interpreted in terms of their distribution. The main interpretation from the data are that as the excavations age:

- Fracture and horizontal offset occurrences increase
- Openings within fractures and separations increase

Table 8-1
Historical Summary of Excavation Effects

Date	Event	Comments
April 1983	Excavation of SPDV Rooms completed.	None.
July 1983	Sounding survey of all underground openings.	All drummy or slabby areas removed by hand or with continuous miner or rock bolted.
August 1985	Floor fracturing identified in SPDV Room 3.	None.
December 1985	Observation holes drilled in Waste Shaft Station.	27 holes drilled in Waste Shaft Station to determine condition of MB139.
May - June, 1986	Supplemental drilling program for newly established Excavation Effects Program (EEP) to investigate conditions in the roof and floor.	30 borehole arrays established throughout the underground (Figure 8-1).
1986	Ground-penetrating radar performed in test rooms as referenced in Borns and Stormont (1988).	Technique was effective in locating first reflector, such as fracture or clay layer, but structures below this were not easily distinguished.
1987	Feasibility study of electromagnetic methods for detection of fluid and fracture zones underground at WIPP.	Study successfully demonstrated use of a direct current resistivity measurement method.
February 1987	Recommendation by Underground Maintenance Committee to cease normal ground maintenance activities in SPDV Room 2 to allow observation of unrestricted deformation.	Scaling and roofbolting prohibited in Room 2.

Table 8-1 (Continued)
Historical Summary of Excavation Effects

Date	Event	Comments
September 1, 1987 to February 12, 1988	The section from Clay G downward in SH shaft station removed by scaling machine.	Action taken because of observed displacements, separations, and fractures in boreholes in shaft station roof and minor separations in some holes drilled into the station floor.
January to May, 1989	Detailed fracture surveys completed in each of the SPDV Rooms.	Surveys performed in response to increased fracturing in SPDV Rooms 1 and 2.
April 5, 1989	South half of SPDV Room 1 evacuated and barricaded.	Extensive continuous fracture system in roof confirmed by drilling operations.
May 4, 1989	North half of SPDV Room 1 and all of SPDV Room 2 evacuated and barricaded.	Intensive fracture mapping in these two rooms indicated that they should be barricaded.
May 1989	Time Domain Reflectometry cables installed in SPDV Rooms 2 and 4.	Time Domain Reflectometry cables measure rock displacements based on electromagnetic signals caused by changes in cable geometry.
August 1989	Ground probing radar performed in SPDV Rooms and Panel 1, Room 6.	Improved techniques and equipment able to identify fractures and stratigraphy within the first two meters.
March and June 1990	Ground probing radar performed in SPDV Rooms, the underground core library, and Panel 1, Room 6.	Improved analytical techniques able to determine radar velocities and differentiate between brine and air filled fractures.
June 1990	SPDV Room 3 barricaded.	Radar and roof soundings indicated incompetent ground.
June 19, 1990	Rock fall in experimental Room A2.	Slab is estimated to be 1-2' thick and has a triangular plan view, estimated to be 70' long and 18' wide.

Table 8-1 (Continued)
Historical Summary of Excavation Effects

Date	Event	Comments
September 1990	Cribbing in N1100 and N1420 drifts.	Cribs were installed in the entrances to SPDV Rooms 1, 2, and 3, and experimental Rooms A1 and A3.
October 1990	Cribbing at experimental Room A2.	Cribs were installed in the entrances to the room.
February 4, 1991	Rock fall in SPDV Room 1.	Size of slab is estimated to be 150' X 33' X 6'.
March 1991	Cribbing in N1100 and N1420 drifts.	Cribs were installed in the entrances to experimental Rooms A, B, and D.
April 1991	Ground support at S-1950, E-300 overcast.	Straps and roofbolts were emplaced on both sides of the overcast to provide additional ground support for the area.
May 3, 1991	Rock fall in experimental Room A2.	Slab dimensions are estimated to be 18' X 30" X 18".
May 23, 1991	Rock falls in experimental Room A1.	Two separate falls occurred within 15 minutes of one another. Combined size estimated to be 50' X 18" X 18".
March - May 1991	Northern section of E140 resized.	E140, N1420 to S90, was resized to 14' X 25'.
August 1991	N460 resized.	N460, E0 to E140, was resized to 13' X 25'.
September 1991	Roof maintenance in E140 drift.	Extensive roof maintenance was performed on the west side of the E140 drift at approximately S1450.
December 1991	Ground support installed in Panel 1, Room 1.	A supplementary roof support system was installed in Panel 1, Room 1 to address project Test Phase requirements.
March 1992	Ground support installed in Waste Shaft Station.	A cable-support ground control system was installed in the eastern brow of the Waste Shaft.

Table 8-1 (Continued)
Historical Summary of Excavation Effects

Date	Event	Comments
June 1992	Ground support installed in E140 drift.	A ground control system approximately 50 feet in length and consisting of wire mesh, cable lacing and mechanical anchored roofbolts was installed in E140 drift at approximately \$1500.
October 1992	Extension of E300 drift creation of N250 drift.	A N250 drift was created between E140 and E300. The E300 drift was extended to N250. Various alcoves were mined to the north and east from E300.
January 1993	Ground support installed in Air Intake Shaft station.	A ground control system approximately consisting of cables and resin-anchored roofbolts was installed on both station brows.
February 1993	Mesh installed on roof of new E300/N250 shop.	Installation of short resin anchored suspension bolts and welded wire mesh on the roof of the new E300 maintenance shop.

Figure 8-1
Borehole Locations for the Excavation Effects Program

Figure 8-2
Typical EEP Borehole Arrangement

Table 8-2
Cumulative Data from Excavation Effects Program

Percent of Holes with Fracturing	Hole E (%)	Hole A (%)	Hole C (%)	Hole F (%)	Hole B (%)	Hole D (%)	All Root Holes (%)	All Floor Holes (%)	All Holes (%)
1986	22	28	22	29	46	36	24	37	30
1987	41	52	41	46	62	64	44	57	51
1988	52	64	52	54	65	71	56	63	60
1989	63	80	67	61	69	71	70	67	68
1990	78	88	78	71	77	79	81	76	78
1991	81	88	78	71	77	79	82	76	79
1992	81	92	89	71	77	79	87	76	81
1993	81	92	89	71	81	79	87	77	82

Notes:

1. Section locations are shown on Figure 8-1.
2. Typical hole configuration is shown on Figure 8-2.
3. Observations were made using a probe consisting of a nail attached perpendicular to the end of a rod.
4. Observations from previous surveys were used for inaccessible holes.
5. Percentages for 1991, 1992, and 1993 do not reflect data obtained from Arrays 31 through 37.

Table 8-2 (Continued)
Cumulative Data from Excavation Effects Program

Percent of Holes with Horizontal Offsetting	Hole E (%)	Hole A (%)	Hole C (%)	Hole F (%)	Hole B (%)	Hole D (%)	All Roof Holes (%)	All Floor Holes (%)	All Holes (%)
1987	63	32	63	21	35	21	53	26	39
1988	78	44	85	32	46	43	70	40	55
1989	85	60	89	46	54	46	78	49	63
1990	89	64	93	54	58	54	82	55	68
1991	89	80	93	54	62	54	87	56	71
1992	93	80	93	57	62	54	89	57	73
1993	93	84	93	57	62	54	90	57	73

Notes:

1. Section locations are shown on Figure 8-1.
2. Typical hole configuration is shown on Figure 8-2.
3. Observations were made using a probe consisting of a nail attached perpendicular to the end of a rod.
4. Observations from previous surveys were used for inaccessible holes.
5. Percentages for 1991, 1992, and 1993 do not reflect data obtained from Arrays 31 through 37.

- Relative displacement at horizontal offsets increases.

Horizontal offsets in the roof usually occur at clay seams or within the first few inches of the roof as shallow spalls. The majority of these offsets are observed near the ribs, with the portion of the borehole from the collar to the offset moving towards the center of the excavation. Horizontal offsets in the floor are generally associated with fractures that define large, shallow, dish-shaped slabs.

Horizontal displacements prevented inspection beyond the displacements in twenty-eight percent of the boreholes available for inspection in 1993. Access into many of the floor holes is not possible due to horizontal offsetting or infilling with salt debris.

8.1.2 Results

Fractures and separations in the subsurface of excavations may be present before inspection boreholes are drilled. Twenty-eight percent of all fractures recorded this year contained openings of 0.13 inch or greater. The largest of these occur within the first two feet of the excavations as shallow spalls.

Horizontal displacements, or offsets, develop after drilling. Results from the survey are presented in two groups to separate offset information for boreholes drilled at different times. In 1986, 161 roof and floor boreholes (Arrays 1-30) were drilled. Offsets were first recorded for many of these holes in 1987. Eighteen additional roof holes (Arrays 31-36) were drilled in 1991. Arrays 31, 32, and 33 are located in the eastern section of N1420 drift. Arrays 34, 35, and 36 are located in Room 3. Offsets were first recorded for these holes in 1992. Array 37 was drilled in 1993 in the newly mined section of E300 and contains six roof and floor holes.

Arrays 1-30

Fractures have been recorded in 87 percent of all roof holes in the Arrays 1-30 since 1987. During this reporting period, fractures were recorded in 58 percent of roof holes available for inspection. Holes not inspected include those blocked by equipment or located in barricaded areas. Seventy-eight percent of these fractures contained openings of 0.13 inch or less; 0.5 inch was the maximum recorded opening. Twelve percent of the roof fractures recorded in 1993 occurred at clay seams. In general, floor fractures in 1993 have vertical

openings no greater than 0.13 inch and are often associated with Marker Bed 139. Openings greater than six inches have been observed in the floor near the ribs in the SPDV Rooms in past inspections and are associated with shallow, dish-shaped slabs.

Horizontal offsets have occurred in 90 percent of all roof holes in Arrays 1-30 since 1986. A maximum increase of one inch relative displacement at any offset was recorded during this reporting period. Horizontal offsets have occurred in 57 percent of floor holes. A maximum annual relative displacement of at least 1.13 inches occurred in one floor hole. Fifty-four percent of recorded offsets occurred at clay seams. Several arrays are inaccessible (Table 8-3).

Arrays 31-36

Eighty-three percent of the boreholes in arrays 31 through 36 contained fractures in 1993. Maximum openings of up to 0.75 inch were found within the first two feet of the boreholes and were associated with small roof bolted spalls. Thirteen percent of recorded fractures occurred at clay seams.

Offsets have developed in seven of the nine boreholes in Arrays 31, 32 and 33 (N1420) with maximum total relative displacement of one inch at any offset and a maximum annual displacement of 0.38 inch at any offset. Seven of the nine boreholes in Arrays 34, 35, and 36 (Room 3) contain offsets. Maximum relative displacements were one inch. Fifty-four percent of offsets in arrays 31 through 36 occurred at clay seams. Array 37 was inspected about five weeks after drilling. Offsets of 0.13 inch relative displacement had developed in two roof holes. Tight fractures were found in four of the six holes. This excavation was about eight months old at the time of inspection.

8.2 Fracture Mapping of Excavation Surfaces

Maps of surface fractures are created for areas of the WIPP underground facility as required. During this reporting period surface-fracture maps were produced to assist in ground stability assessments for the following areas:

- Room 7, Panel 1 - Roof
- Air Intake Shaft Station - Roof

Table 8-3
Inaccessible Arrays

Array	Last Survey Date	Comment
4	1990	Not accessible
5	None	Blocked by SNL experiment
6	1990	Not accessible
7	1989	Not accessible
8	1989	Not accessible
9	1989	Not accessible
10	1989	Not accessible
16	1989	Holes are filled with muck
26	1988	Not accessible

- N1420 (Substation 2A to Room D) - Roof

8.2.1 Room 7, Panel 1 - Roof Fractures

Fractures in the roof in Room 7 were mapped in January, 1993. Comparisons with similar maps created in 1992 reveal that the overall lengths of most existing fractures along the east rib and room center did not increase significantly. The linear extent of fracturing along the west rib, however, had almost doubled.

The majority of fractures occur within approximately seven feet of the ribs as low-angle fractures with dip angles estimated at less than twenty degrees. The extent of fracturing into the rock has been measured to 2.2 feet in the past, but generally, the openings are too small to allow accurate measurements to be made. Fracture depths were not estimated or measured during this survey.

Barred-down areas on the west side of the room had been enlarged. At least two previously mapped, low-angle fractures had extended near the west rib and new fractures had appeared. The appearance of fractures along the east rib remained relatively unchanged.

There was an increase in fracturing along the center of the room. Most of these fractures are just beginning to appear and dips were not apparent. A set of previously mapped fractures along the centerline at the north end of the room remain unchanged.

8.2.2 Air Intake Shaft Station - Roof Fractures

The surface fractures in the Air Intake Shaft station roof and lowermost portion of the shaft were mapped in September and October 1992. Fractures mapped in the station area include those in the station roof and in the north and south brows. Fractures in the shaft were mapped from the station roof to Clay I (about twenty feet above the roof). The station roof was mined to the base of Anhydrite "b". The ribs were offset along the base of the anhydrite approximately 1.5 inches into the station and the moving salt had covered the edges of at least one rockbolt plate installed at the east rib/roof intersection for mesh support. The brows were offset toward the shaft along the base of the anhydrite. Fractures developed in the anhydrite as a result of this movement.

South of the shaft, separations up to two inches wide were observed along the top and base

of Anhydrite "b", indicating that the layer formed a thin slab, typically about 1-1/2 inches to two inches thick (Figure 8-3). Several vertical fractures were exposed in the anhydrite between the shaft and the south brow, probably extending through the anhydrite to the horizontal separations along the top of the layer.

Separation of the north brow occurred along the base of Anhydrite "b". The horizontal extent of the separation was measured with a steel tape at forty-eight inches. Vertical separation was 0.5 inch.

The brows are mined approximately forty-five degrees down and away from the shaft and extend approximately 13 feet horizontally. Seven major fracture groups in the south brow face were mapped. These fractures propagate perpendicularly from the face and have visible apertures of up to one inch. Fractures in the north brow exhibit more continuity across the face of the brow than in the south brow. Figure 8-3 provides an approximation of fracture propagation in the brows as they would probably appear in cross section.

The bases of both brows contain fractures within five feet of the brow faces. These fractures open vertically into the brow with visible apertures ranging from less than 0.06 inch to 0.25 inch.

Depths were not determined for the majority of the fractures in the station area because the fractures were inaccessible, or had apertures too narrow to allow measurement with a steel tape. Depths of up to one foot were visually estimated in some cases.

Fractures within the shaft were located below Anhydrite "a", with the exception of one fracture on the west side of the shaft located approximately one foot above the anhydrite. Fracture apertures and offsets were visually estimated at up to one inch as no direct depth measurements were possible. The geology surrounding some of the larger fractures on the east and southeast sides of the shaft was masked by powdered material from drilling activities. Less than 0.5 inch of horizontal displacement (into the shaft) had occurred along the bottom of Anhydrite "a" on the east side of the shaft. Photographs taken of fractures to the south side of the shaft during previous geological mapping activities were compared with those taken during the current fracture mapping activities and no significant changes were noted.

Anhydrite "b" is exaggerated four
times for illustration purposes

Figure 8-3
Air Intake Shaft Station - Brow Face

8.2.3 N1420 Roof Fractures

Fractures in the roof in the eastern section of N1420 were mapped in January 1993. The mapped area extends from Room D (E1694) to Substation 2A (E561). Excavation from Room D to E818 (beginning of ramp-down) lies at the experimental level with the roof approximately four to five feet below Clay I. Anhydrite "a" is visible in the ribs at approximately eight feet above the floor while Anhydrite "b" lies about one foot above the floor. The excavation ramps down from the experimental horizon at E818 to the facility horizon at E604. Within the ramp area there are two brows, one at E730 at Anhydrite "a" and one at E604 at Anhydrite "b".

Fracturing in the roof along the ribs was virtually continuous from Room D to the beginning of the ramp. These rib side fractures often curved around miters at intersections, but rarely continued across the intersections. Near-rib fractures were absent in the roof between the brows in the ramp area, but resumed in the lower brow for approximately 23 feet along the roof. These fractures typically occur approximately one foot from the ribs and propagate at a low angle into the roof beam toward the center of the drift. Fracture openings were typically 0.06 inch to 0.13 inch, with a maximum of one inch.

Fractures propagating vertically into the roof were concentrated in three areas. The roof between the mitered corners at the intersection of N1420 and Room C2 contained several vertical fractures oriented parallel with the centerline of N1420. Maximum openings at the excavation were 0.13 inch. A section of roof, approximately 17 feet long, between Rooms A3 and A2 contained several vertical fractures oriented perpendicular to the drift and one oriented parallel with the drift, intersecting most of the other fractures. Maximum openings at the excavation were 0.13 inch. Excavation Effects Program Array 32, located in the area of vertical fracturing between rooms A3 and A2, revealed fractures concentrated within 2.1 feet of the excavation. Offsetting of the rib boreholes had occurred with up to 0.62 inch displacement of the beam below Clay I toward the center of the drift. Maximum separation at Clay I (approximately 4.5 feet above the roof) was 0.06 inch. Maximum separation at any fracture within the boreholes was 0.75 inch.

A section of roof approximately ten-feet long between Rooms A2 and A1 contained two vertical fractures oriented perpendicular to the drift with a maximum opening at the excavation of 0.06 inch.

Convergence between the ribs in the ramp area is apparent from the fractures in the vertical exposures, or faces, of the brows located in this area. The face of the brow in the upper portion of the ramp terminates at Clay H. The brow is offset up to 1.5 inches toward the east along the clay. The absence of fractures in the base of the brow is attributed to the location of Clay G (exposed in the ribs) which confines the horizontal load to the ribs below the clay and allows them to offset into the excavation.

The face of the brow in the lower portion of the ramp terminates at Clay G and displays fracturing very similar to that of the upper brow. The brow is offset to the east less than 1.5 inch along the clay. The base of this brow contains near-rib fractures.

8.3 Observations of Rockbolt Failures

During this reporting period, each reported rockbolt failure was documented as close to the time of failure as possible and recorded in a database. Some observed failures were noted for inclusion in the database, although the actual dates of failure are unknown. Information recorded for each failure include, when possible, the type of failure, location, bolt length and diameter, plate type, and any unusual condition associated with the installation.

8.3.1 Failure Mechanisms

For the purposes of this section, rockbolt failures are divided into three categories as follows:

- Bolt head separating from shaft
- Bolt breaking along shaft
- Anchor, plate, and other failures.

Bolt head failure occurs when the head of the bolt separates from the bolt shaft. The bolts usually have not exhibited necking near the breaks. The cause of this type of failure probably can be attributed to conditions causing the bearing plate to be placed at an angle not perpendicular to the bolt axis, which results in the bolt head becoming unevenly loaded as the salt deforms (Figure 8-4). The induced bending moment causes the bolt head to break off. Over-torquing may impart high and uneven initial bolt loads, exacerbating other conditions which might lead to failure.

Failures occurring along the bolt shafts typically exhibit some degree of bending near the broken ends, indicating that lateral forces were exerted on the bolts. Inspections of observation boreholes located near many of these failures often reveal slip-planes (usually clay layers) lying at approximately the same distance from the excavations as the zones of bolt breakage.

A small number of bolts experienced failure when the anchor assemblies failed or slipped down the bolthole. These failures are probably associated with the installation procedure or conditions at the anchor position.

8.3.2 Failure Locations

Roofbolt failures were found at various locations throughout the underground facility during this reporting period. Two thirds of these failures were, or are suspected to be, shaft failures. The remainder were primarily head failures. These failures usually occurred in the rows of bolts nearest the rib.

8.3.2.1 E300 Shop: N1100 to N1420

Bolt failures in this area (except one head failure) occurred, or are suspected to have occurred, along the shafts. Wire mesh was installed on the roof to prevent broken bolts from falling. Bolts that failed after installation of the mesh are recorded as probable shaft failures and account for the total suspected shaft failures for this reporting period. Suspected and actual shaft failures in this area account for 40 percent of the total bolt failures in the underground this year.

The recovered shaft failures were inspected and 72 percent were found with bending in the bolts at the breaks, which typically occur between six and seven feet from the heads. The bolt deformation results from lateral displacements at the first stratigraphic contact, shown by core logs to approximately 6.5 feet above the roof in this drift. Break surfaces typically exhibit indications of brittle failure; necking has not been observed.

The bolt failures are concentrated within the bolt rows nearer the ribs. These bolts typically exhibit some degree of bending at the breaks which is associated with lateral movement at Anhydrite "b", evident in observation boreholes located in the roof of the shop. Because these bolts were installed almost immediately after excavation, they were probably affected

Figure 8-4
Schematic of Roofbolt Installation

by the early high deformation of the rock immediately after excavation, whereas most pattern bolts in other areas of the facility were installed some years after excavation.

8.3.2.2 N1420, E300 Alcove

A relatively high number of bolts have broken in this area with seven shaft failures recorded this year. The failures occurred in a brow located at the north of the alcove. The bolts broke approximately 9.5 feet from the heads, in the threaded portions. All except one of the bolts exhibited bending at the breaks from lateral displacement along Clay G.

8.3.2.3 Panel 1

Bolts installed in Rooms 1 through 6, Panel 1, are ten-feet long and penetrate Clay G. Bolts installed in Room 7 and the S1600 and S1950 access drifts are six-feet long and do not penetrate Clay G. Panel 1 bolt failures, recorded during this reporting period, were primarily head failures. One bolt broke along the shaft in Room 6 and it is anticipated that similar failures will occur in the panel rooms as lateral movement progresses along the clay. Silicon sealant present in these installations may prevent some broken bolts from falling from the holes and thus being observed and recorded.

8.3.2.4 Waste Shaft Station

Two types of failures occurred in the Waste Shaft station area this year. Head failures occurred in old, welded-head type installations near the bulkhead west of the shaft. Shaft failures occurred in the station, usually near the north rib. The breaks were typically 6.5 to 7 feet from the heads. Anhydrite "b" was found to lie approximately 6.4 feet above the roof in observation boreholes located in the station.

8.3.2.5 General

Other areas experiencing several roofbolt failures included 'e west end of the S1300 Shop (primarily in the north alcove), the Salt Shaft Station, and W30 at approximately S1200. Failures in these areas are primarily head failures and are attributed to non-vertical installations, installations in the rib-roof corners, or installation too closely following excavation.

The database of rockbolt failures is updated as bolts fail. Investigations into the causes and impacts of rockbolt failures in the underground are made as additional data are collected.

9.0 Summary

At the start of the project, criteria were developed which address the requirements for the design of the WIPP. These criteria (DOE, 1984) cover all aspects of the facility and its operation as a pilot plant for the demonstration of technical and operational methods for permanent isolation of contact- and remote-handled transuranic waste. These criteria are compared with conditions actually observed in the underground from July 1992 to June 1993 (Table 9-1).

Fracture development in the roof is primarily caused by the concentration of compressive stresses in the roof beam and is influenced by the shape of the excavation and the stratigraphy in the immediate vicinity of the opening. The buildup of stress, with time, causes differential movements along stratigraphic boundaries. Pillar deformations induce lateral compressive stresses into the immediate roof and floor. Stratigraphic boundaries cause differential movements which are observed as horizontal offsetting in Excavation Effects Program boreholes and as bending deformations in failed roof bolts. Large strains associated with lateral movements in the roof, can induce fracturing in the roof which is frequently seen near the ribs. The presence of horizontal offsetting confirms that lateral movements occur in the roof beam.

The in-situ performance of the excavations generally continue to satisfy the appropriate design criteria, although specific areas are being identified where deterioration due to aging of the facility must be addressed through routine maintenance and implementation of engineered systems. Deterioration due to aging of the facility has been identified through the analysis of data acquired from geomechanical instrumentation. In addition to underground instrumentation, qualitative assessments of the fracture development are documented through mapping of the underground repository and inspections of the excavation effects boreholes and observation boreholes. The information acquired from these processes provide early detection of ground deterioration and contribute to the design of ground support systems that retard deterioration of unstable ground.

From the latest evaluation of the yielding supplementary roof support system in Room 1, Panel 1 it was concluded that the system continues to function in accordance with design

specifications. This evaluation is based on investigation of observation boreholes, and geomechanical instrumentation located in the room. In addition, the rock stratum in which the support system is anchored appears to be stable.

Table 9-1
Comparison of Excavation Performance to Design Criteria

Criterion (DOE, 1984)	Description	Comments
Chapter 5: Design Criteria, Underground Item 2: Ground Control a: Shaft Design	"Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and for the period of time thereafter required for decommissioning of the facility."	Water pressure observed on piezometers located behind the shaft keys remains below design levels. Geomechanical data indicate that the Salt Handling, Exhaust, and Waste Shafts are structurally stable.
	"The time dependent closure of shafts due to salt creep shall be considered in the design of shafts. Shafts shall be dimensioned so that the minimum dimensions required for shaft functions are maintained for the entire design life."	Closure of the shafts remain within design requirements.
	"Groundwater inflow to the shaft shall be controlled so that no uncontrolled groundwater reaches the storage horizon via the shafts."	The small amount of groundwater inflow into the AIS has been controlled through grouting.
c. Mine Design	"...deformation of excavations and pillars shall remain within the limits required for structural function, ventilation, and safety."	Pillars remain stable. Deformation of excavations remain within the required limits. In E140 north of the Salt Handling Shaft, high deformation rates have been attributed to areas of nearby mining. High deformation rates in SPDV Room 2 indicate that a roof fall is expected to occur in April or May of 1994. The room is currently barricaded and access to N1100 and N1420 is restricted.
	"Rock bolts shall be used where necessary to provide positive support of roofs and walls."	Rock bolts have been installed throughout the underground to aid in roof and wall support. Failures have been documented and will be studied further as additional data become available.

Table 9-1 (Continued)
Comparison of Excavation Performance to Design Criteria

Criterion (DOE, 1984)	Description	Comments
d. Emplacement Criteria	"The underground storage rooms and access drifts shall be compatible with the waste transport vehicles and with the waste container sizes, shapes, weights, stacking configurations, and the handling and backfilling equipment requirements... . The storage rooms shall be sized for efficient handling and stacking of the CH waste containers."	<p>Access Drifts Geomechanical instrument data and visual observations indicate that the current design is compatible with emplacement criteria. Closure rates indicate access drifts will require periodic trimming in order to provide clearances for equipment. The storage rooms and access drifts have been sized to permit transportation and storage of the CH TRU waste.</p> <p>Underground Storage Rooms Geomechanical instrument data and visual observations indicate that the current design is compatible with emplacement criteria.</p>
e. Retrievalability	"All waste placed into the WIPP are retrievable, with retrievalability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes. The storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of ten years."	Ground control was implemented in Panel 1 to ensure access into rooms during the Demonstration Phase. Delays in using Panel 1 and changes in its use have required additional remedial measures to be taken. These include trimming of the floors, backfilling of the floor fractures, and the installation of supplementary roof support in some areas.
f. Instrumentation	"Underground instrumentation is required to measure phenomena important to the performance of the facility or which cannot be otherwise quantified. Instruments shall be provided to measure such phenomena as rock behavior, gases, seismic activity, and groundwater pressures in order to confirm or revise design assumptions."	<p>Geotechnical instrumentation is operated and maintained to meet the requirements of this criteria.</p> <p>The panel of geotechnical experts indicates that the monitoring program at the WIPP has been proven adequate, specifically with regard to the instrumentation in Room 1, Panel 1.</p>

Note: CH = Contact Handled
SPDV = site Preliminary Design Validation

10.0 *References*

DOE - See U.S. Department of Energy

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