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LONG-TERM GROUND CONTROL PLAN FOR THE WASTE ISOLATION PILOT PLANT

WESTINGHOUSE ELECTRIC CORPORATION
WASTE ISOLATION DIVISION
GEOTECHNICAL ENGINEERING

June 1997

Processing and final preparation of this report were performed by the Westinghouse Electric Corporation's Waste Isolation Division, the management and operating contractor for the Waste Isolation Pilot Plant, under U.S. Department of Energy contract DE-AC04-86AL31950.

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is designed to permanently dispose of transuranic radioactive waste left from the research and production of nuclear weapons. Transuranic waste consists of clothing, tools, rags, and other such items contaminated with trace amounts of radioactive elements, mostly plutonium. Located in southeastern New Mexico, 26 miles east of Carlsbad, project facilities include disposal rooms excavated in an ancient, stable salt formation, 2150 feet (655 meters) underground This deep geologic setting requires that a comprehensive ground control program be in place to monitor and assure the stability of the underground openings and address issues of concern.

The primary objective of the WIPP ground control program is to provide a safe environment for personnel and equipment in a manner that is consistent with the operational objectives of the facility, primarily waste disposal. The ground control program is a concerted and centralized activity responsible for providing a continuing assessment of the capabilities of the underground openings to achieve that objective. The fundamentals on which the ground-control program at WIPP is based are as follows:

- Ground stability is maintained as long as access is required.
- Ground-control maintenance efforts increase with the age of the openings.
- Ground-control plans are specific but flexible.
- Regular ground-control maintenance is required

The extensive geotechnical monitoring program provides a high degree of confidence in the ability to predict and mitigate ground control issues before they become safety problems. The evaluation of ground conditions is a continuous process. The Westinghouse Waste Isolation Division's Geotechnical Engineering Department gathers and evaluates data from various sources on a daily and weekly basis. This information is formally presented in bimonthly and annual reports.

A comprehensive evaluation of the ground conditions and support systems throughout the facility is performed annually. The latest evaluation was performed in October 1996. To aid in the performance of these evaluations and to facilitate data gathering and presentation, the underground facility is divided into zones. Geotechnical Engineering evaluates each zone based on visual observations, analyses of geomechanical instrumentation data, fracture data from observation boreholes, rockbolt

failure data, and ground support instrumentation data. A database is maintained that documents the current status of each zone with respect to opening geometry, excavation age, ground support mechanisms, and operational use.

The operating life of parts of the underground facility may extend to approximately 50 years from the date of the first excavations. Over time, the stress conditions around the underground excavations result in degradation of those excavations. The roof beam receives the greatest amount of attention regarding ground control because its stability is closely related to safety. An unexpected roof fall presents great potential for harm to personnel, equipment, and waste containment systems. The vast majority of ground control activities are related to monitoring, evaluation, and corrective action of roof stability concerns. To a lesser degree, the safety and operational issues of floor heaving and of rib spalling are also addressed. In general there are three options for addressing potentially hazardous ground control issues. Those options are

- Support the ground
- Remove the ground
- Close the area

With respect to supporting the ground, an extensive database of information on ground control systems directly related to conditions in the WIPP underground has been developed. As the excavations aged, issues associated with the roof beam began to develop, and most of the facility was pattern bolted with mechanical-point-anchor rockbolts. With the exception of ductile deformation, these bolts provide a rigid support system while the rock formation is constantly moving in response to differential stresses. These rigid systems have a finite life, and supplemental systems are required in areas scheduled for long-term use. Supplemental systems are installed in several areas including most of Panel 1. Resin-anchored threaded-bar bolts are the predominant system in use; however, several types of yielding systems are also installed and being evaluated. Monitoring of installed supplemental systems will continue to create a larger base of information for ground control system selection. In addition, an *in situ* and laboratory testing program is in place to evaluate alternative options for ground support.

Excavation alternatives with respect to existing openings generally mean removal of the roof beam. Beam removal activities at the salt shaft station and in the East-140 Drift were successfully completed and prove this to be a viable alternative in areas of advanced beam deterioration.

The option to close openings to access generally applies to areas that have a limited useful purpose, or to those that from an economical and/or safety standpoint should be closed rather than maintained. All areas north of North-780 are now closed, eliminating safety concerns as well as maintenance costs for those areas. The option to close select areas of Panel 1 at some future time is also available.

The criteria for ground control design and implementation are based on long-term objectives, experience, performance of existing systems, laboratory and *in situ* tests of selected ground control components and/or systems, numerical analyses, and a vast amount of site-specific geotechnical data which have been accumulated since the site opened. The criteria may be modified to accommodate technological advances, geologic conditions, or operational changes. In accordance with established requirements, the design of ground control systems shall provide ground control instrumentation and equipment capable of monitoring ground stability and roof support adequacy.

One of the more difficult aspects of ground control is determining the criteria and evaluating the data that indicate when ground control actions should be initiated. The identification of instabilities is critical to maintaining a safe underground environment. The process followed at WIPP includes evaluation of four general categories of information that include the following:

- Geomechanical instrumentation data.
- Performance of installed ground support systems
- Physical observations.
- Comparison to previous experience.

With closure of the experimental areas of the underground facility and with the anticipated receipt of waste, ground control activities will increasingly be related to waste receipt schedules and operational considerations. Panel 1 continues to support a variety of regulatory compliance activities that are scheduled to be completed before first waste receipt. Keeping Panel 1 operationally ready for waste receipt supports the requirements of the Resource Conservation and Recovery Act (RCRA) permit application. Geotechnical, operational, and other performance information derived from Panel 1 is also used to demonstrate compliance in regulatory documents required for initiation of disposal operations, including the following:

- RCRA Part B Permit Application
- Compliance Certification Application.

Long-term plans and options for Panel 1 usage have a direct impact on ground control activities for the area. Evaluation of specific areas and recommendations for remedial ground control procedures must be made in a time frame that allows for implementation of those procedures prior to waste emplacement. Under all options, general maintenance activities, such as scaling down small pieces of rock and replacing identified broken bolts as required, would continue in all accessible areas. The identified options are as follows:

- Use all of Panel 1.
- Receive first waste in Panel 1 and use as much of the panel as possible.
- Receive first waste in Panel 1 and move to Panel 2 as soon as possible.
- Close Panel 1 and begin initial waste emplacement in Panel 2.

The ground control program is evolving. Activities that are planned, recommended, or in progress include:

- Expand the geotechnical monitoring program, as required, to ensure adequate coverage of the facility.
- Expand the use of the Ground Control Monitoring System (GCMS) in the overall Geotechnical Information System.
- Continue to evaluate new support technologies with application to WIPP, including installation of yielding systems.
- Install Titan Load Indicators on the threaded-bar bolts in Room 1, Panel 1.
- Increase the monitoring frequency in Room 7, Panel 1, during and following the floor removal process.
- Continue to evaluate and refine rockbolt safety restraints.

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ground conditions at WIPP to ensure safe and reliable operational conditions from the present time to closure of the facility.

1.2 Scope

Primary areas of concern to ground control issues are addressed and presented here in summary form. Reports such as the annual *Geotechnical Analysis Report* (GAR) (U.S. Department of Energy, 1996a) and the *Panel 1 Utilization Plan 1996 Update* (Garcia, 1996) are referenced throughout this document and supply more detailed geotechnical and programmatic information. This document addresses technical aspects of the underground facility that are concerned with the design, construction, and performance of the subsurface geologic structures and support systems. In particular, this plan addresses the requirement for maintaining the ground conditions of the underground facility in a safe and operational state for its projected life.

Issues associated with the stability of the roof of the underground facility are the primary focus of this document. With the anticipated receipt of waste in 1998, this document provides additional detail to Panel 1 activities and options. Stability of the four shafts is addressed with regard to routine maintenance. Conditions of the ribs and floor are discussed briefly with respect to maintenance and their relationship to the roof. Also presented are methods by which proposed support systems and materials are, and will continue to be, evaluated and utilized.

2.0 BACKGROUND

Drilling of the Salt Handling Shaft began in 1981 and was followed by the initiation of underground excavation in 1982. Since that time, over 7 miles (11.3 kilometers) of drifts, rooms, and alcoves have been excavated. The excavations vary in geometry, geology, age, and operational use. These parameters affect the selection of ground control measures; but the ability of the salt to creep or flow with time, and the related fracture process, has the greatest impact on selection of ground control systems. All ground control mechanisms are subjected to the salt-creep forces.

The ground control program at WIPP consists of many aspects which include continuous visual inspections of the underground openings, extensive geomechanical monitoring, numerical modeling, analysis of rockbolt failures, implementation of ground control procedures, and comprehensive *in situ* and laboratory testing and evaluation of ground control components and systems. The knowledge and experience acquired over the years has enabled the ground control program to evolve from one that was somewhat generic to underground mining to one that is more WIPP specific. That is, the program is focused on the ground control events most often encountered in the facility and also to operational considerations such as waste disposal schedules and requirements. The roof in the underground receives the greatest amount of attention because the structural integrity of the roof is a safety, as well, as an operational concern. The ribs and floor are also subject to creep-deformation effects and require periodic maintenance such as scaling and milling.

Delays in the schedule for waste receipt have resulted in the ground control program addressing the necessity of maintaining openings for a longer period of time than originally anticipated, particularly for Panel 1. Conversely, with the conclusion of the experimental programs, several areas of the facility were closed (deactivated), including all areas north of North-780, eliminating potential safety concerns, as well as, maintenance requirements and associated costs for those areas. The development of plans for areas that involve waste handling/emplacement are based on the modified "Repository Waste Emplacement Schedule" (Garcia, 1996) The schedule presented herein has been modified from that presented in Garcia, 1996, to reflect a six month delay in receipt of waste (U.S. Department of Energy, 1997a).

The ground control program has produced a better understanding of the failure mechanisms acting on the roof beam and the associated support systems. As the database of information grows with time, the ability to preserve and maintain optimal ground conditions and to predict and/or mitigate hazardous conditions increases.

The history of ground control at WIPP is an important record of what has been learned. Many ground control issues that once presented new challenges have become commonplace as have the methods to address those issues. A wide variety of ground control issues have been encountered at WIPP, ranging from minor spalling to monitored roof falls. A summary of ground control activities that have been implemented at the site is presented in Appendix A.

2.1 <u>Current Status of Underground Openings</u>

The underground has been divided into zones, based primarily on location, for the purpose of evaluating and documenting their current status. Figure 2-1 presents a layout of the facility with the numeric identification of each zone. Table 2-1 lists statistical information on each zone, such as area description, roof beam dimensions, opening geometry, excavation age, ground support, and operational use. This table also gives the projected life of the zone based on its operational use.

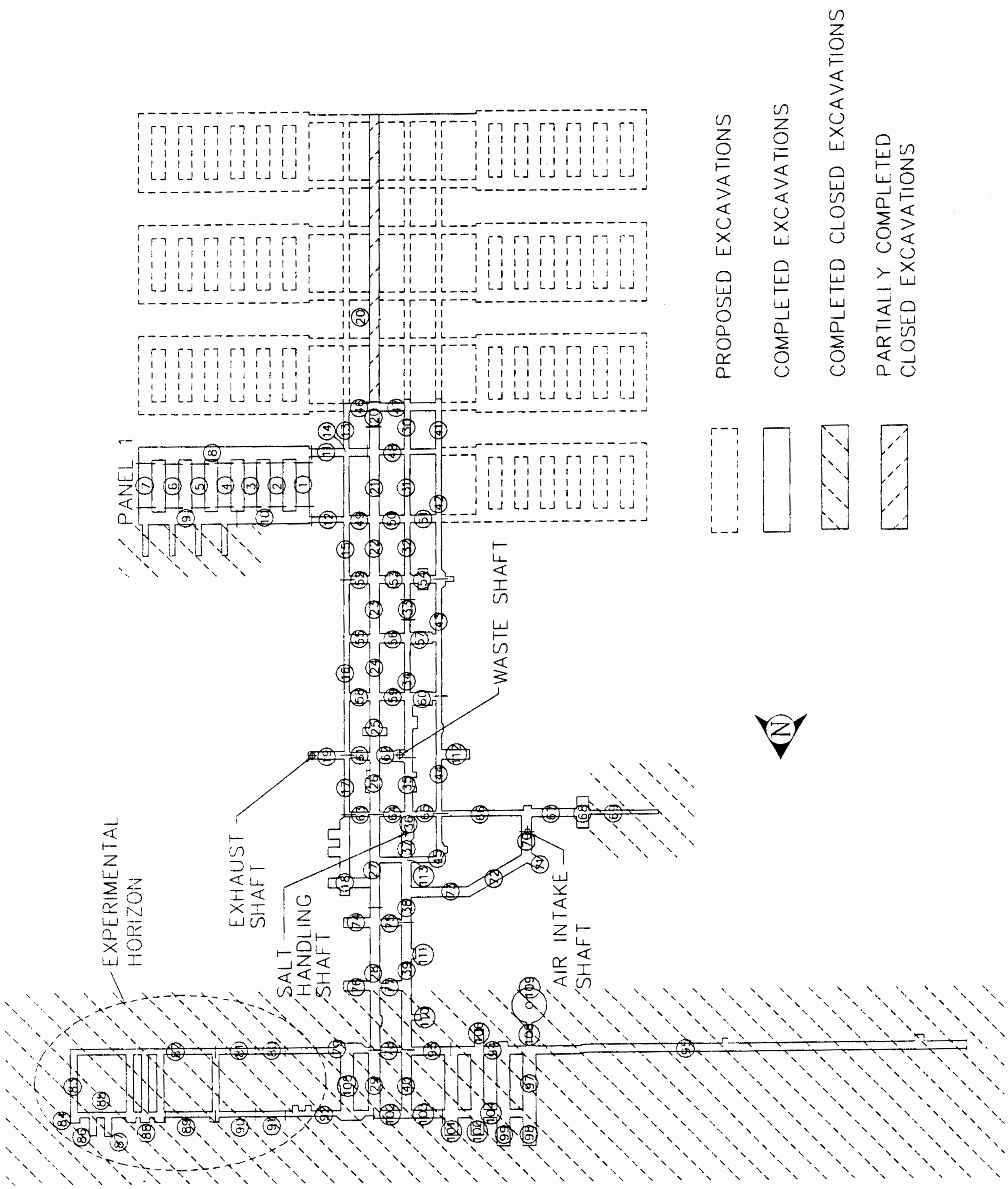

Figure 2-1. WIPP Underground Assessment Zones

Table 2-1. Underground Assessment Zones – Statistical Information (Page 1 of 3)

Zone Number	Area Description	Opening Dimensions (ft.)	Use	Age (yr.)	Est. Life	Bolt Length (ft.)	Bolt Diam. (in.)	Bolt Type	Patt. Bolt Spacing (ft.)	Roof Beam Dimensions (ft.)
1	ROOM 1 PANEL 1	13x33	WASTE DISP	11	ST	13	1.000	THRB	SPCIAL	7x33
2	ROOM 2 PANEL 1	13x33	WASTE DISP	10	ST	99	9.999	VARY	VARIES	7x33
3	ROOM 3 PANEL 1	13x33	WASTE DISP	10	ST	13	0.875	THRB	4.5SQ	7x33
4	ROOM 4 PANEL 1(N/2)	13x33	WASTE DISP	9	ST	12	0.875	THRB	4.5SQ	7x33
4	ROOM 4 PANEL 1(S/2)	13x33	WASTE DISP	9	ST	13	0.875	THRB	4.5SQ	7x33
5	ROOM 5 PANEL 1	13x33	WASTE DISP	9	ST	12	0.875	THRB	4.5SQ	7x33
6	ROOM 6 PANEL 1	13x33	WASTE DISP	9	ST	12	0.875	THRB	4.5SQ	7x33
7	ROOM 7 PANEL 1	13x33	WASTE DISP	9	ST	12	0.875	THRB	5x3.8T	7x33
8	S1950 PANEL 1	13x33	WASTE DISP	11	ST	13	0.875	THRB	4.5SQ	7x33
9	S1600 R4-R7 PANEL 1	13x33	WASTE DISP	9	ST	13	0.875	THRB	4.5SQ	7x33
10	S1600 R1-R4 PANEL 1	13x33	WASTE DISP	10	ST	13	0.875	THRB	4.5SQ	7x33
11	S1950P1 ENT E140-300	13x20	HAULAGE	12	ST	6	0.625	MECH	5x2.5T	7x20
11	S1950P1 ENT E300-520	13x20	HAULAGE	11	ST	6	0.625	MECH	5x2.5T	7x20
12	S1600 PANEL 1 ENTRY	12x14	VENTILATE	11	ST	6	0.625	MECH	5x2.5T	8x14
13	E300 S1950-S2180	12x14	VENTILATE	11	LT	10	0.750	MECH	4x2TRI	8x14
14	E300 OVERCAST-S1950	15x19	VENTILATE	11	LT	0	0.000	NONE	NONE	5x19
15	E300 S1300-S1600	12x14	VENTILATE	12	LT	6	0.625	MECH	5x2.5T	8x14
15	E300 S1600-S1950	12x14	VENTILATE	12	LT	10	0.750	MECH	5x2.5T	8x14
16	E300 S400-S1300	12x14	VENTILATE	13	LT	10	0.750	MECH	5x2.5T	8x14
17	E300 S90-S400	12x14	VENTILATE	12	LT	10	0.750	MECH	6x3TRI	8x14
18	E300 S90-N250	15x25	SHOP	5	I	0	0.000	NONE	NONE	5x25
19	EXHST DRIFT E OF 300	12x20	VENTILATE	14	LT	10	0.750	MECH	5x2.5T	8x20
20	E140 S OF 2180	8x25	CLOSD AREA	14	CL	0	0.000	MECH	UNKNWN	6x25
20	E140 S2050-S2180	15x25	HAULAGE	14	LT	8	0.750	MECH	12x3TR	5x25
21	E140 S1600-S1950	20x25	HAULAGE	14	LT	4	0.625	MECH	5x5TRI	6x25
21	E140 S1950-S2050	15x25	HAULAGE	14	LT	8	0.750	MECH	12x3TR	5x25
22	E140 S1300-S1600	20x25	HAULAGE	14	LT	5	0.625	MECH	5x5TRI	6x25
23	E140 S1000-S1300	15x25	HAULAGE	14	LT	8	0.750	MECH	12x3TR	5x25
24	E140 S700-S1000	15x25	HAULAGE	14	LT	8	0.750	MECH	12x3TR	5x25
25	E140 S400-S700	15x25	HAULAGE	14	LT	8	0.750	MECH	12x3TR	5x25
26	E140 S90-S400	15x25	HAULAGE	14	LT	10	0.750	MECH	5x2.5T	5x25
27	E140 N250-N460	15x25	HAULAGE	14	LT	10	0.750	MECH	5x2.5T	5x25
27	E140 S90-N250	15x25	HAULAGE	14	LT	10	0.750	MECH	5x2.5T	5x25
28	E140 N460-N780	15x25	HAULAGE	14	LT	99	9.999	VARY	VARIES	5x25
28	E140 N780-N1100	15x25	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	5x25
29	E140 N1100-N1400	15x25	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	5x25
30	W30 S1950-S2180	12x14	ACCESS	9	LT	10	0.750	MECH	5x2.5T	8x14
31	W30 S1600-S1950	12x14	ACCESS	11	LT	10	0.750	MECH	6x3TRI	8x14
32	W30 S1175-S1300	12x14	ACCESS	13	LT	10	0.750	MECH	5x2.5T	8x14
32	W30 S1300-S1600	12x14	ACCESS	13	LT	6	0.625	MECH	5x3TRI	8x14
33	W30 S1150 BOOST FAN	20x25	VENTILATE	13	LT	6	0.750	MECH	4x6SQ	6x25
34	W30 S400-S700	12x20	ACCESS	13	LT	10	0.750	MECH	5x3TRI	8x20
34	W30 S700-S1125	12x14	ACCESS	13	LT	10	0.750	MECH	5x3TRI	8x14
35	W30 S90-S400	12x20	HAULAGE	15	LT	10	0.750	MECH	5x2.5T	8x20
36	SALT SHAFT STATION	20x33	STATION	15	LT	5	0.625	MECH	8x5TRI	6x33
37	E0 SALT STA-N150	12x25	HAULAGE	15	LT	6	0.625	MECH	5x3TRI	8x25
38	E0 N150-N460	12x25	HAULAGE	14	LT	10	0.750	MECH	5x2.5T	8x25
39	E0 N460-N780	12X25	HAULAGE	14	LT	10	0.750	MECH	5x2.5T	8x25
39	E0 N780-N1100	12x25	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	8x25
40	E0 N1100-N1400	12x25	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	8x25

Table 2-1. Underground Assessment Zones – Statistical Information (Page 2 of 3)

Zone Number	Area Description	Opening Dimension (ft.)	Use	Age (yr.)	Est. Life	Bolt Length (ft.)	Bolt Diam. (in.)	Bolt Type	Patt. Bolt Spacing (ft.)	Roof Beam Dimensions (ft.)
41	W170 S1950-S2180	12x14	HAULAGE	9	LT	10	0.750	MECH	5x2.5T	8x14
42	W170 S1300-S1600	12x14	HAULAGE	13	LT	10	0.750	MECH	5x2.5T	8x14
42	W170 S1600-S1950	12x14	HAULAGE	13	LT	10	0.750	MECH	5x2.5T	8x14
43	W170 S1000-S1300	12x14	HAULAGE	13	LT	10	0.750	MECH	6x3TRI	8x14
43	W170 S700-S1000	12x14	HAULAGE	13	LT	10	0.750	MECH	6x3TRI	8x14
44	W170 S90-S700	12x14	HAULAGE	13	LT	10	0.750	MECH	6x3TRI	8x14
45	W170/N150 S90/E0	12x14	HAULAGE	13	LT	10	0.750	MECH	6x3TRI	8x14
46	S2180 E140-E300	13x20	HAULAGE	11	I	10	0.750	MECH	5x2.5T	7x20
47	S2180 W30-E140	13x20	HAULAGE	9	I	10	0.750	MECH	5x2.5T	7x20
47	S2180 W30-W170	13x20	HAULAGE	9	I	10	0.750	MECH	5x2.5T	7x20
48	S1950 W30-E140	12x14	CROSS DRFT	11	I	10	0.750	MECH	5x2.5T	8x14
48	S1950 W30-W170	12x14	CROSS DRFT	10	I	10	0.750	MECH	5x2.5T	8x14
49	S1600 E140-E300	12x20	CROSS DRFT	12	I	10	0.750	MECH	6x4TRI	8x20
50	S1600 E140-W30	12x20/27	CROSS DRFT	13	I	10	0.750	MECH	5x3TRI	8x20/27
51	S1600 W30-W170	12x20	CROSS DRFT	12	I	10	0.750	MECH	5x2.5T	8x20
52	S1300 E140-E300	12x25	VENTILATE	13	I	10	0.750	MECH	5x3TRI	8x25
53	S1300 E140-W30	12x20	OFFICES	13	I	6	0.625	MECH	6x3TRI	8x20
54	S1300 W30-W170	14x20	SHOP	13	I	99	9.999	MECH	4x2TRI	6x20
55	S1000 E140-E300	12x20	CROSS DRFT	12	I	10	0.750	MECH	5x5TRI	8x20
56	S1000 E140-W30	12x25	CROSS DRFT	13	I	10	0.750	MECH	5x2.5T	8x25
57	S1000 W30-W170	12x33	OFFICES	12	I	10	0.750	MECH	5x2.5T	8x33
58	S700 E140-E300	14x33	SHOP	13	I	10	0.750	MECH	5x5TRI	6x33
59	S700 E140-W30	12x20	HAULAGE	12	I	10	0.750	MECH	6x3TRI	8x20
60	S700 W30-W170	12x32	OFFICES	13	I	6	0.625	MECH	5x2.5T	8x32
61	S400 E140-E300	VARIES	VENTILATE	14	LT	10	0.750	MECH	5x3TRI	VARIES
62	WASTE SHAFT STATION	16x22	STATION	14	LT	10	0.750	MECH	5x5TRI	4x22
63	S90 E140-E300	12x12	ACCESS	12	LT	10	0.750	MECH	5x2.5T	8x12
64	S90 E0-E140	12x25	ELECT SUBS	12	I	0	0.000	NONE	NONE	8x25
65	S90 W30-W170	12x14	ACCESS	12	LT	10	0.750	MECH	5x2.5T	8x14
66	S90 W170-AIS	12x14	VENTILATE	9	I	10	0.750	MECH	6x3TRI	8x14
67	S90 AIS-Q	12x20	EXPERIMENT	8	ST	10	0.750	MECH	6x3TRI	8x20
68	Q ALCOVE	15x30	EXPERIMENT	8	ST	6	0.625	MECH	6x6TRI	5x30
69	Q ROOM	9.5RND	CLOSD AREA	8	CL	0	0.000	MECH	NONE	N/A
70	AIS STATION AT SHAFT	20x25	STATION	9	LT	12	0.750	MECH	6x6TRI	6x25
70	AIS STATION LOW BRWS	12x25	STATION	9	LT	6	0.750	MECH	6x6TRI	8x25
71	ROOM V	12x25	EXPERIMENT	9	ST	4	0.750	MECH	5x2.5T	8x25
72	AIS ACCESS N215	13x25	VENTILATE	9	LT	10	0.750	MECH	5x2.5T	7x25
73	N300 0E-WEST	13x25	VENTILATE	9	LT	10	0.750	MECH	5x3TRI	7x25
74	E140 N460 ALCOVE	13x25	OFFICES	6	I	10	0.750	MECH	5x2.5T	7x25
75	N460 E0-E140	13x25	ACCESS	14	I	10	0.750	MECH	6x3TRI	7x25
76	E140 N780 ALCOVE	13x25	STORAGE	6	I	10	0.750	MECH	5x2.5T	7x25
77	N780 E0-E140 SHOP	13x25	SHOP	14	I	10	0.750	MECH	5x2.5T	7x25
78	N1100 E0-E140	12x14	CLOSD AREA	14	CL	10	0.750	MECH	4x5TRI	8x14
79	N1100 E140-E300	12x24	CLOSD AREA	13	CL	6	0.750	MECH	5x2.5T	8x24
79	N1100 E300-RAMP	9x14	CLOSD AREA	13	CL	10	0.625	MECH	5x5TRI	8x14
80	N1100 RAMP	9x14	CLOSD AREA	13	CL	6	0.750	MECH	5x2.5T	VARIES
81	N1100 RAMP-ROOM B	9x14	CLOSD AREA	13	CL	6	0.750	MECH	5x2.5T	8x14
82	N1100 ROOMS B-D	9x14	CLOSD AREA	13	CL	6	0.750	MECH	5x2.5T	8x14
83	ROOM D	18x18	CLOSD AREA	13	CL	10	0.875	THRB	5x5TRI	5x14

Table 2-1. Underground Assessment Zones – Statistical Information (Page 3 of 3)

Zone Number	Area Description	Opening Dimension (ft.)	Use	Age (yr.)	Est. Life	Bolt Length (ft.)	Bolt Diam. (in.)	Bolt Type	Patt. Bolt Spacing (ft.)	Roof Beam Dimensions (ft.)
84	ROOM M	11x24	CLOSD AREA	13	CL	4	0.625	MECH	5x5SQ	6x24
85	N1400 ROOMS A3-D	12x14	CLOSD AREA	13	CL	6	0.750	MECH	4x3TRI	5x14
86	ROOM C-1	18x18	CLOSD AREA	13	CL	10	0.750	MECH	5x2.5T	5x14
87	ROOM C-2	18x18	CLOSD AREA	13	CL	10	0.750	MECH	5x3TRI	5x14
88	N1400 ROOMS A1-A3	12x14	CLOSD AREA	13	CL	6	0.625	MECH	4x3TRI	5x14
89	N1400 ROOMS A1-B	12x14	CLOSD AREA	13	CL	6	0.625	MECH	5x3TRI	5x14
90	N1400 RAMP-ROOM B	12x14	CLOSD AREA	13	CL	6	0.625	MECH	4x3TRI	5x14
91	N1400 RAMP	12x14	CLOSD AREA	13	CL	10	0.750	MECH	5x2.5T	VARIES
92	N1400 E140-RAMP	12x14	CLOSD AREA	13	CL	10	0.625	MECH	5x2.5T	8x14
93	N1100 E0-SPDV RM1	12x20	CLOSD AREA	14	CL	10	0.750	MECH	5x5TRI	8x20
94	N1100 SPDV ROOMS 1-4	12x20	CLOSD AREA	14	CL	10	0.750	MECH	5x5TRI	8x20
95	ROOM G AND G	10x20	CLOSD AREA	12	CL	10	0.750	MECH	VARIES	10x20
97	SPDV ROOM 4	13x33	CLOSD AREA	14	CL	10	0.750	MECH	5x5TRI	7x33
98	ROOM L-4	13x33	CLOSD AREA	8	CL	10	0.750	MECH	5x2.5T	7x33
99	ROOM L-3	13x33	CLOSD AREA	8	CL	10	0.750	MECH	5x2.5T	7x33
100	ROOM L-2	13x33	CLOSD AREA	13	CL	10	0.750	MECH	4x2TRI	7x33
101	ROOM L-1	13x33	CLOSD AREA	13	CL	10	0.750	MECH	5x2.5T	7x33
102	N1420 E0-E140	12x20	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	8x20
103	N1400 E0-ROOM L1	12x20	CLOSD AREA	14	CL	10	0.750	MECH	5x2.5T	8x20
104	N1400 ROOMS L1-L4	12x20	CLOSD AREA	14	CL	10	0.750	MECH	4x4TRI	8x20
105	E300 N1100-1400 SHOP	13x33	CLOSD AREA	8	CL	10	0.750	MECH	5x2.5T	7x33
106	ROOM J	12x23	CLOSD AREA	13	CL	10	0.750	MECH	4x4TRI	8x23
108	ROOM H ACCESS	10x11	CLOSD AREA	13	CL	99	0.750	MECH	5x5TRI	10x11
109	ROOM H	10x36	CLOSD AREA	12	CL	99	9.999	MECH	5x5TRI	10x36
110	N940 ALCOVE 0E	12x14	CLOSD AREA	8	CL	10	0.750	MECH	6x3TRI	8x14
111	E0 N620 ALCOVE	12x25	OFFICES	8	I	10	0.625	MECH	5x2.5T	8x25
112	W170 CORE STORAGE	13x25	STORAGE	8	ST	10	0.750	MECH	5x2.5T	7x25
113	E0 N150 OVERCAST	20x15	VENITLATE	10	LT	10	0.750	MECH	4x4SQ	7x15
114	N150 OVERCAST-E140	10x14	VENITLATE	14	LT	10	0.750	MECH	8x4.5T	10x14

Note: For evaluation purposes, Zone 96 was combined with Zone 95, and Zone 107 was combined with Zone 94.

Age is calculated using the date of this printing and the date of completion of the first excavation sequence. The date of printing is May 7, 1997.

Zeros (e.g., 0.000) in a numerical column indicate that no information is available. Nines (e.g., 9.999) in a numerical column indicate multiple types or dimensions.

Key:

ST	- Short-term	THRB	- Threaded-Bar Bolt
I	- Intermediate	MECH	- Mechanical Anchor
LT	- Long-term	TRI	- Triangular
CL	- Closed	T	- Triangular
		SQ	- Square

(Refer to text for detailed definitions)

2.1.1 Geology

The underground facility horizon lies within the Salado Formation. The basic constituents of the formation are nearly horizontal beds of clear halite (salt), argillaceous halite, and polyhalitic halite. A detailed geologic discussion of the Salado Formation can be found in Holt and Powers (1984). Two mining horizons are located within the facility horizon: (1) the disposal horizon and (2) the experimental horizon. Within these horizons are seams of anhydrite and clay that have a significant impact on the stability of openings and the selection of ground control systems. All openings in the experimental horizon are closed and no longer accessible; therefore, any reference relative to this horizon is limited to historical perspective. Figure 2-2 shows the typical stratigraphy at the WIPP facility horizon.

It is recognized that localized geologic conditions can have a considerable impact on the stability of an opening. Fracture development at a specific location, within a roof beam, for example, may be influenced by the clay content or other seemingly minor factors.

Disposal Horizon

The stratigraphic location of the disposal rooms is within the disposal horizon. All accessible underground openings are located within this horizon, and all ground control activities presented in this LTGCP are related to this level. A thin seam of anhydrite identified as Anhydrite "b" defines the upper boundary of the disposal horizon. A 20-inch thick to 32-inch thick (0.5 to 0.8-meter thick) persistent bed of anhydrite, identified as Marker Bed 139 (MB 139), defines the lower boundary of the disposal horizon. These boundary distinctions are defined for the purpose of this LTGCP only and may not coincide with permit definitions.

In relationship to Panel 1 disposal rooms with a 13-foot (4-meter) excavation height, clay F is typically found just below the roof. Anhydrite "b" is located approximately 6.5 feet (2 meters) above the roof and is underlain by clay G. Anhydrite "a" is located approximately 13 feet (4 meters) above the roof and is underlain by clay H. MB 139 typically lies about 5 feet (1.5 meters) below the floor; however, removal of floor material in Panel 1, Room 7, will place the marker bed closer to the opening in that

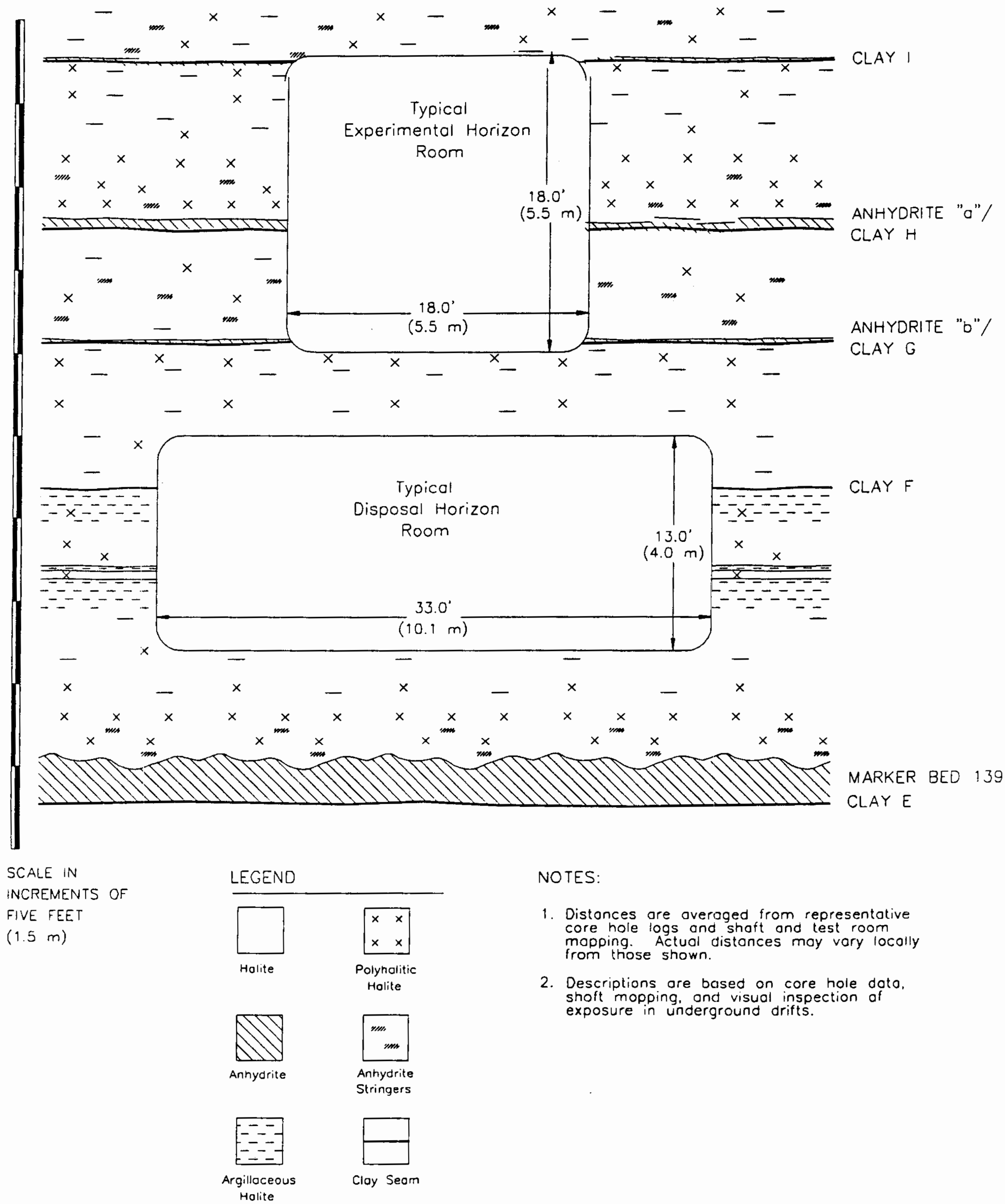

Figure 2-2. Typical Stratigraphy at the WIPP Facility Horizon.

area. MB 139 is underlain by clay E. Anhydrite "a" is approximately 8.5-inches (0.2-meter) thick, and Anhydrite "b" is approximately 2.5-inches (0.1-meter) thick. The clay seams associated with the anhydrite layers are approximately 0.25-inch (6-millimeters) thick. Clay F is not a well-defined seam but is laterally discontinuous within the halite. The clay layers provide surfaces along which slip can occur, whereas the anhydrite layers are stiff units that do not creep. In addition, the undulating top of Marker Bed 139 resists shear movement along the interface with the overlying salt (U.S. Department of Energy, 1993).

2.1.2 General Ground Conditions

Because salt is a rock that creeps when subjected to load, once an opening is made, a continuous process of deformation and associated fracturing is initiated. These creep-related processes play a dominant role regarding the physical condition of the excavation. In turn, the ground conditions in an excavation are a primary controlling factor influencing the type of ground control measures that will be used.

Roof beam conditions in general follow a predictable path of deterioration over time, with the degree of degradation varying significantly throughout the facility. Many areas have remained stable since their excavation, while low-angle fracturing and bed separation are observed in other areas. Low-angle fractures as discussed in this text refers to fractures initiating at or near the rib-roof intersection and propagating upward at an angle less than 45 degrees. These fractures develop from the ribs upward over the center of the room. In areas where this process is advanced, fracturing on one side typically dominates, and a cantilever forms that must be supported to prevent catastrophic failure such as a roof fall.

2.1.3 Panel 1 Ground Conditions

The ground conditions in Panel 1 follow a pattern similar to that observed in the areas of the East-140 Drift where the beam was removed. Low-angle fractures of varying degrees are observed in all areas. The installation of rockbolts has, in many instances, resulted in the thin edge of the wedge associated with a cantilevered beam breaking with an associated vertical fracture that runs roughly parallel to the rib.

Table 2-2 depicts the total vertical and horizontal convergence for the Panel 1 rooms since their dates of excavation. Total vertical convergence is well over 2 feet (0.6 meter) in some areas of the panel and horizontal convergence is over 19 inches (0.5 meter). Because ground control measures have little or no effect on the creep process, convergence of this type will continue unabated until the openings are completely closed. WIPP permit requirements specify that a 13-foot (4-meter) operating clearance (roof to floor) be maintained in the disposal rooms. Therefore, trimming of the floor and ribs in specific rooms may be performed prior to waste emplacement to maintain or achieve the specified opening dimensions.

Table 2-2. Panel 1 – Total Vertical and Horizontal Closure

Room	Date of Excavation at Instrument	Excavation Completed to Final Dimensions	Total Vertical Closure as of Reporting Period[a] (in.)	Total Horizontal Closure as of Reporting Period[a] (in.)
Room 1	June 1986	August 1986	35.16	20.47
Room 2	January 1987	March 1988	27.73	17.09
Room 3	February 1987	March 1988	31.53	21.39
Room 4	February 1988	March 1988	26.85	17.62
Room 5	February 1988	March 1988	26.61	18.56
Room 6	February 1988	May 1988	28.00	16.40
Room 7	March 1988	March 1988	27.79	16.22

(a) Data taken from DRAFT *Geotechnical Analysis Report for July 1995 - June 1996* (U.S. Department of Energy, 1997b).

Data indicate that the majority of Panel 1 excavations show an expansion rate of the roof beam from the exposed surface to Anhydrite "b" to be fairly constant at about 0.5-inch (12.7-millimeters) per year. Roof beam expansion or dilation is a major component of total convergence, and rates in more active areas of the panel have ranged up to 1.8-inches (45.7-millimeters) per year. The more active areas have all had supplemental ground support installed.

2.1.4 General Support System Conditions

Excluding Panel 1, the ground support in most of the accessible areas underground consists of mechanical-anchor rockbolts anchored above the first clay seam. The mechanical-anchor rockbolts used at WIPP employ a wedge-type point anchor. Other than bolts that have noticeably failed, it is difficult (if not impossible) to tell the condition of the remaining bolts. However, based on measured deformation and observed offset since their installation date, it can be surmised that a significant number of the mechanical-anchor rockbolts are probably in material yield or are experiencing anchor slippage. In the northernmost areas of the East-0 Drift and the East-140 Drift where rebolting with threaded-bar bolts and yielding cable bolts was performed, the bolts are relatively new and should be in good condition.

2.1.5 Panel 1 Support System Conditions

Various support systems have been installed in Panel 1 over a several-year time span. The types of systems and their installation dates are specified in Appendix A of this report. As in the other areas of the facility, it is difficult (if not impossible) to tell the condition of the in-place bolts. However, based on measured deformation and observed offset since their installation date, a significant number of the mechanical-anchor rockbolts installed in Rooms 1 through 6 are probably in material yield, are experiencing anchor slippage, or have failed. Silicone was placed in each rockbolt hole during bolt installation, and the silicone holds the bolts in place making it difficult to identify failed bolts. The six-foot-long mechanical-anchor bolts installed in Room 7, South-1600, and South-1950 do not penetrate the first clay seam and have not been exposed to the same degree of lateral and axial deformation as the 10-foot bolts. Because of this, they may be in relatively good condition.

With the exception of parts of Rooms 1 and 2, the entire panel has been rebolted with partially (approximately 3 foot) resin-anchored, threaded-bar bolts. The condition of these bolts varies depending on their date of installation, location, and method of installation. Excluding the mechanical bolts, the threaded bars installed in Room 1 are the oldest system in place in the panel. Although these bolts are being detensioned manually, a few bolt failures, apparently related to offset-induced lateral loading, have been observed. It is known that the vast majority of the bolts are intact because they continue to load and require detensioning. Additionally, specific areas in Room 7 are experiencing increased roof beam activity with failures of threaded-bar bolts being one result.

The remaining threaded-bar systems in the panel are relatively young and should be in good condition. During rockbolt installation, boreholes were oversized below the clay seam to allow for a larger amount of offset prior to the bolts being affected by lateral loading. In addition, the latest installations have the resin column terminated approximately 1 foot above the clay seam to allow for a less severe bend in the bolts once lateral loading begins. However, as these systems age, increased numbers of threaded-bar bolt failures are expected.

Given the modified waste emplacement schedule presented in Section 3.0, it is clear that bolts will fail in increasing numbers and require replacement as the panel ages. Prior to the receipt of waste schedule slipping 6 months until mid 1998, it was estimated that if as many as 25 percent of the pattern bolts in the panel failed before panel closure, and given the sequence for filling the panel, approximately 225 bolts would need to be replaced by 2002. The estimate was extrapolated from current failure data and may change with time. Any schedule acceleration helps mitigate this problem, while schedule delays exacerbate it.

2.2 Monitoring and Evaluation

The assessment and evaluation of the condition of WIPP excavations is an interactive, continuing process involving a wide variety of data. These evaluations can be as simple as the required daily visual site checks by personnel working in an area or as complex as the expert review of Room 1, Panel 1 (U.S. Department of Energy, 1991a). The Geotechnical Engineering group gathers and evaluates data from various sources on a daily and weekly basis. Bimonthly underground geotechnical assessment reports are prepared, as is the annual *Geotechnical Analysis Report.* An in-depth evaluation of all of the accessible underground is performed on an annual basis as part of the preparation of this plan. These evaluations are based on visual observations by Geotechnical Engineering personnel, analyses of instrumentation data, observation borehole data, and rockbolt failure patterns. Roof stability is considered to be of primary interest, while rib and floor stability is secondary.

Remote monitoring of geotechnical conditions and ground support systems in selected locations of the closed areas north of North-780 is also being performed. The monitoring continues to assist in evaluation of systems as they age and trend toward failure. It is intended that data from these zones will provide predictive information on ground falls in areas with installed, although not maintained, roof support systems.

2.2.1 Geotechnical Instrumentation Data

The purpose of the geomechanical monitoring program is to provide *in situ* data to support continuing assessments of the behavior of the underground facilities. Specifically, the program provides the following:

- Early detection of conditions that could compromise operational safety.
- Evaluation of room closure that could affect operational performance.
- Guidance for design modifications and remedial actions.
- Data for interpreting the actual behavior of underground openings, in comparison with established design criteria.
- Data on which to base an accurate assessment of the mechanisms of deformation and fracturing that are taking place.

Geotechnical data collected from each specific ground control zone are evaluated to determine whether conditions exist which would warrant closer attention or possibly immediate attention from a ground control standpoint. For the long term, roof expansion rates, along with the planned useful life of a zone, are important criteria to be considered when selecting ground control measures for that area.

Measurements of roof-to-floor and rib-to-rib closure are taken throughout the underground, both manually and remotely, on a routine basis. In addition to closure data, extensometer data are also collected. Extensometer data, combined with information from observation holes, allow the monitoring of separations at clay seams and within salt beams (beam expansion).

2.2.2 Annual Evaluation

A thorough evaluation of ground conditions and support systems throughout the facility is performed annually, with the latest evaluation being performed in October 1996. Some areas are evaluated more frequently as determined necessary. The annual evaluation provides information necessary to address near-term ground control needs as well as requirements of this long-term plan. The comprehensive annual evaluation of *in situ* conditions and tracking of activities set forth in this LTGCP serve as a means of evaluating the results of the ground control program.

3.0 WIPP GROUND CONTROL ISSUES

The primary objective of the WIPP ground control program is to provide a safe environment for personnel and equipment in a manner that is consistent with the operational objectives of the facility. This means that ground control issues at WIPP fall broadly under two main categories: safety concerns and operational impacts. Under these main categories are many sub-issues that are addressed or evaluated in some fashion when making ground control decisions. These issues include but are not limited to the following:

- Waste disposal schedules, including the rates at which waste is received. This is of particular interest with respect to Panel 1 because of its age.
- Regulatory compliance issues in support of maintaining the current permit status under the Resource Conservation and Recovery Act (RCRA). Additional compliance issues related to other applications (e.g., RCRA part B) must also be addressed.
- Age and life expectancy of areas requiring ground support.
- Roof beam failure scenarios (failure modes and mechanisms).
- Monitoring methods and resultant data, including formation monitoring and ground control system monitoring.

- Ground control system selection and design.
- Ground control system performance characteristics in relation to formation movement, formation failure modes, and system component failure modes.
- Timing of implementation. Supplemental systems are installed or alternative actions are implemented when monitoring indicates a potential for unstable conditions and well before a hazardous condition exists.

Panel 1 presents several ground control issues with the most critical aspect being maintenance of safe conditions for waste disposal operations. The panel, because of its age, provides ground control challenges that are not typical of newly mined excavations. These challenges are not insurmountable, and the technical approach to these issues may be simpler than addressing the regulatory issues associated with abandoning the panel, including the time required to excavate and prepare another panel.

3.1 Roof Beam

The roof beam, as defined in Section 1.0, receives the greatest amount of attention regarding ground control because of its related safety concerns. An unexpected roof fall presents great potential for harm to personnel, equipment, and waste containment systems. The issues highlighted above and the vast majority of ground control activities are related to monitoring, evaluation, and corrective action of roof stability concerns. To a lesser degree, the safety and operational issues of floor heaving and spalling of the ribs are also addressed.

3.1.1 Time-Dependent Degradation and Roof Beam Fracture Development

An undisturbed stress field exists in the rock prior to mining. When an excavation is made, that stress field is disturbed, creating differential stresses that result in creep, and as a result, convergence of the room. With time, the stresses close to the excavation are relieved by deformation of the salt into the excavation. The strata interfaces (clay and anhydrite seams) do not provide much, if any, shear resistance, resulting in differential stresses and related strains developing above and below the seams. This differential movement concentrates the stresses in the beam and, with time, produces an offset in boreholes penetrating the seams, including rockbolt holes. The stresses in the roof beam result from the related processes of bending, dilation, and shearing, which all take place continuously. Any one of these processes may predominate at any particular time. The concentration of stresses and strain in the roof beam may reach values high enough to cause (or at least initiate) a fracture process. This process can, and commonly does, culminate in the form of low-angle fractures. The formation of the low-angle fractures is a result of a complex combination of creep-related compressive (horizontal) forces with gravity and creep-related vertical forces. Gravity and creep related deformation produce a downward bowing of the beam most prominent near the center of the opening. The sagging of the beam, coupled with the horizontal forces and orientation of bedding planes, creates a horizontal or sub-horizontal en-echelon fracture sequence (i.e., the initial fractures are offset to the left or right of each other like a series of steps). These fractures ultimately connect to form the low-angle fractures. They terminate where they reach a discontinuity in the stratigraphy, such as a clay seam. This fracture pattern is common in salt and potash mines and is illustrated in Figure 3-1. Observations made during the beam-removal activities in the East-140 drift indicate that if separation at clay G occurs, that separation may be located near the upper terminus of the low-angle fracture as opposed to in the center of the drift as depicted in Figure 3-1.

3.1.2 Roof Beam Failure Patterns

The fracture mechanisms have proven to be consistent in areas experiencing advanced degradation of the roof beam. The monitored roof falls in Site and Preliminary Design Validation (SPDV) Rooms 1 and 2 indicate that a detached section of a roof beam will be somewhat of a wedge shape. Observations of the fracture patterns exposed during the beam removal process in the East-140 Drift confirm this mode of failure. Knowledge of the type of failure that can be expected in the roof beam aids in the design of ground support systems. For example, support systems designed to support the entire cross-sectional area of the roof beam are considered conservative, based on a wedge-type failure. Figures 3-2 and 3-3 illustrate the types of fracture patterns and bolt loading that are typically observed in the roof beam. Figure 3-3 shows that by keeping the end of the resin column approximately 1 foot (0.3 meter) above the clay seam rather than flush with it, the bolts will be subjected to a less severe bend as a result of offset. Observations also show the salt to flow around the bolts resulting in a less severe bend. The offset of the bolts as shown in the figures is exaggerated for illustrative purposes.

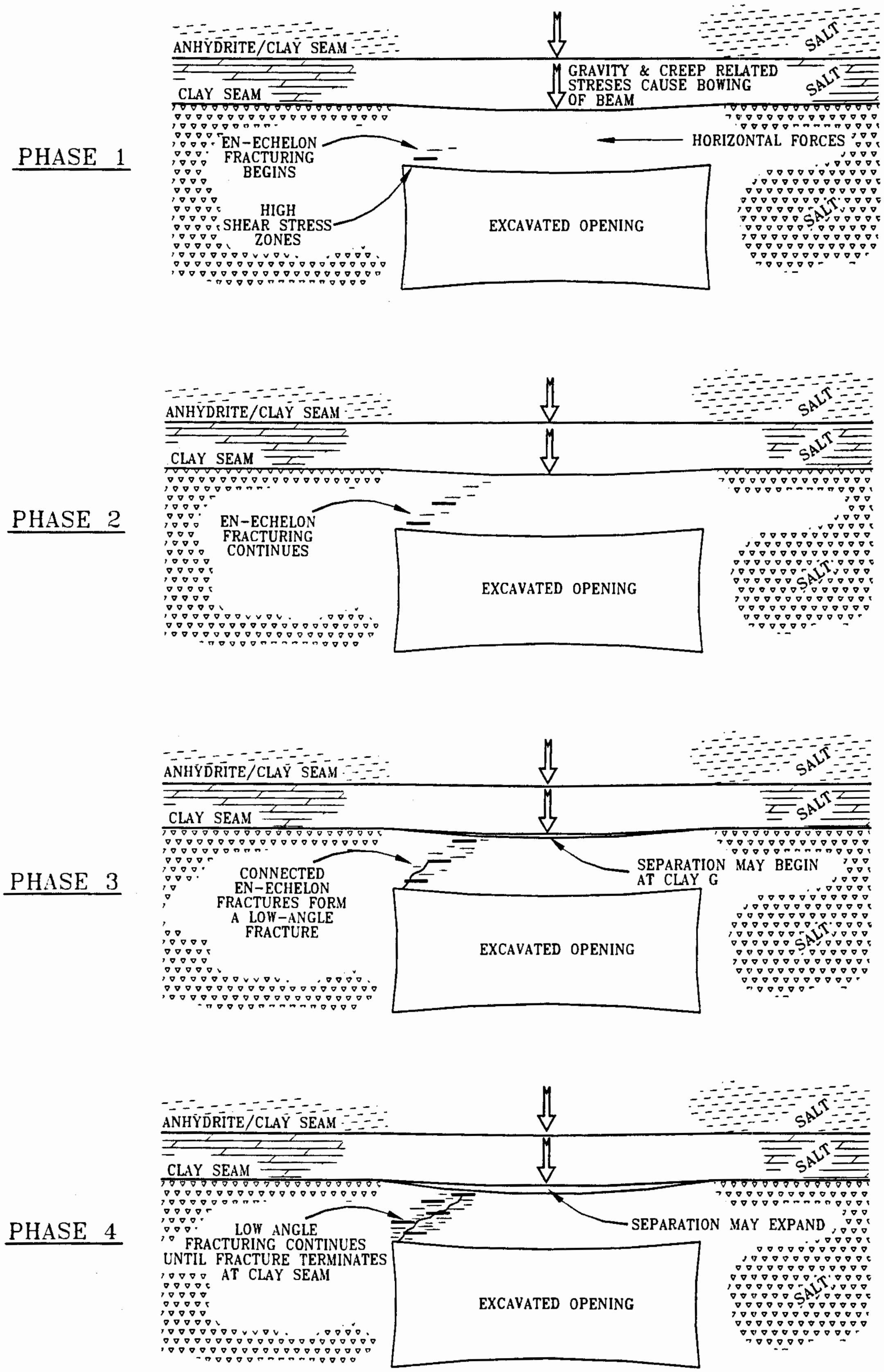

Figure 3-1. Generalized Fracture Development Sequence

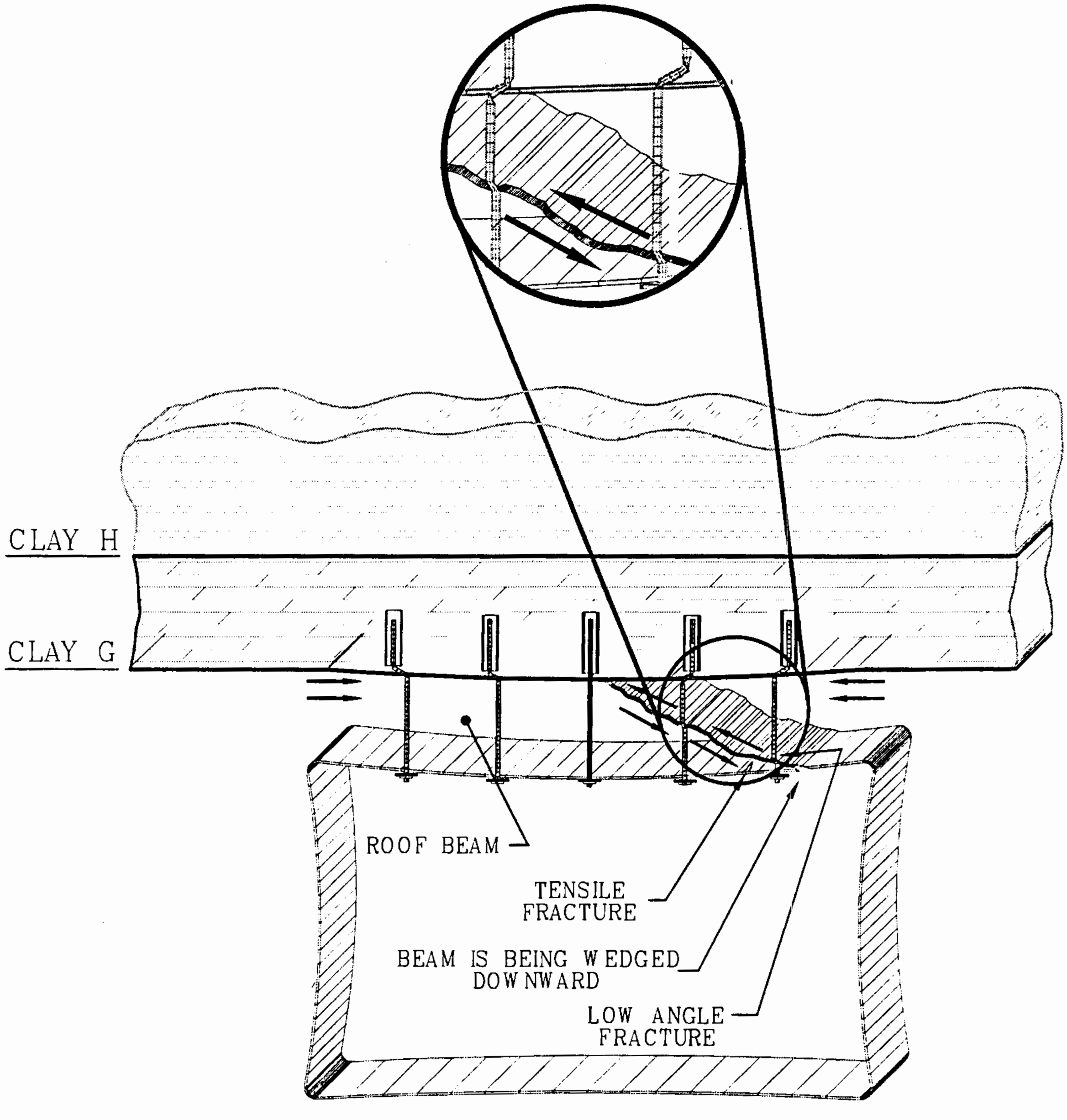

Figure 3-2. Typical Roof Beam Fracturing

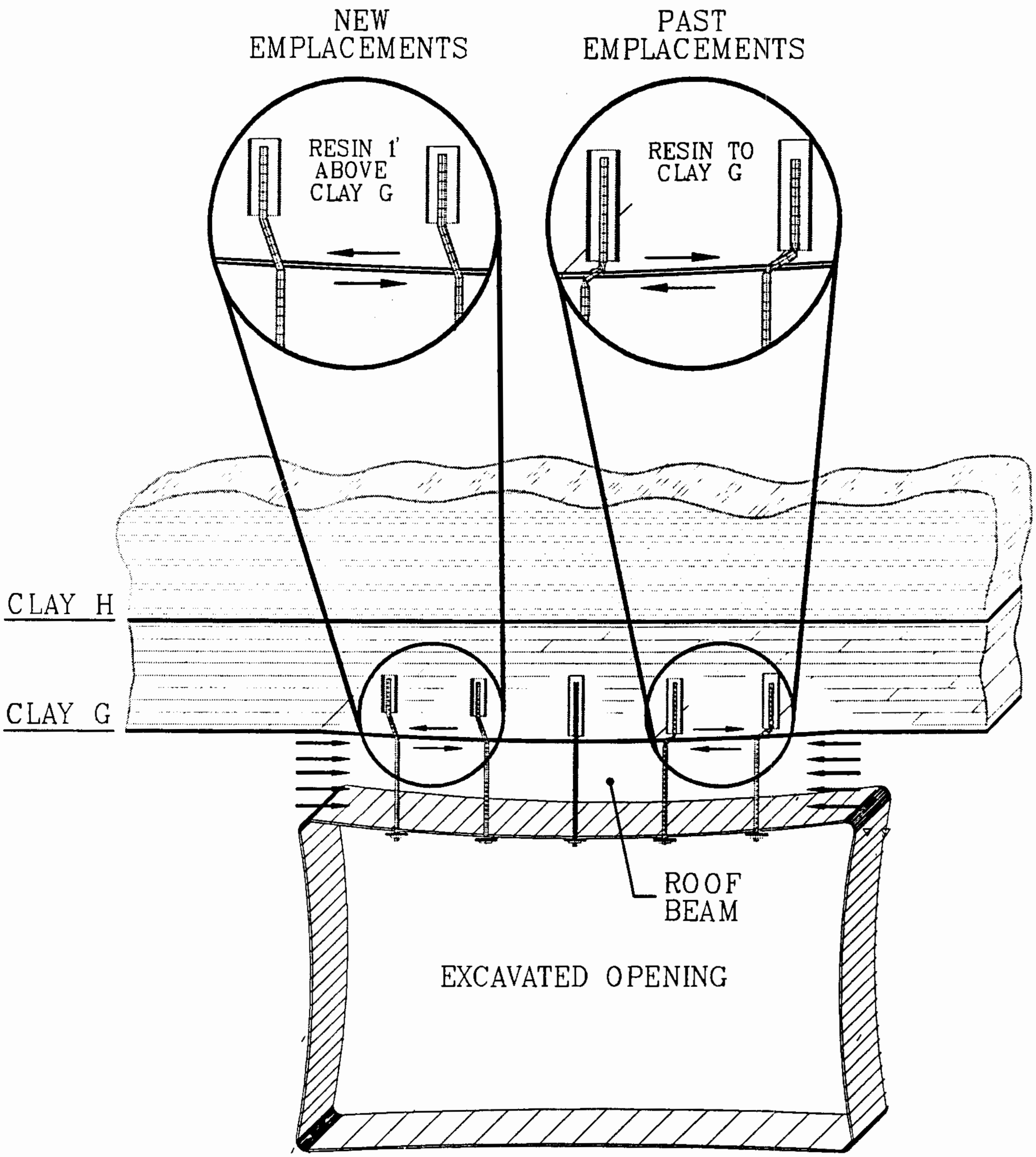

Figure 3-3. Roof Beam Offsetting and Related Bolt Loading

3.2 Rib and Floor Maintenance

The ribs and floor of the underground openings do not have the potential for becoming a safety hazard to the extent that the roof does; nonetheless, safety issues can develop and are addressed. Examples of potentially unsafe conditions include spalling rib rock, tripping hazards associated with floor heave, and vehicular hazards associated with floor heave. Rib and floor maintenance are also performed to address operational concerns. Mine Operations scales the ribs with a mechanical scaler or continuous miner as a necessary part of routine maintenance activities, and some areas have chain-link or polyethylene mesh installed on the rib to control minor spalling. Because the drifts are also travelways, the floors are periodically milled with a floor planer as necessary to maintain a relatively smooth surface.

Floor preparation is a planned activity in support of waste emplacement. Floors will be trimmed to provide a flat smooth working surface and to ensure appropriate working clearances. As an example, in the case of Room 7, more than a foot (0.3 meter) of floor was recently removed using the continuous miner. Removing this amount of material required a transition ramp down into the room.

Maintenance of the ribs and floor is generally considered separately from the roof when making ground control decisions for specific areas. Although the effects should be minimal, any intact rock removed from the ribs and floor has the potential to affect the geomechanical response in the immediate area.

3.3 Rockbolt Failures

Rockbolt failures have occurred throughout the underground facility. Initially, many of the failures were bolt head failures. Currently, the majority of bolt failures appears to be associated with lateral movement at clay G. In addition, nearly all bolt failures to date have involved mechanical-anchor rockbolts, which is primarily related to their age, quantity, and date of installation with respect to date of excavation. However, systems employing threaded-bar bolts (e.g., Room 1 and Room 7, Panel 1) are aging, and failures of these bolt types are also increasing. To date, Room 7, Panel 1, has experienced the greatest number of threaded-bar bolt failures.

Observable rockbolt failures are recorded, and a database on failure locations and modes of failure is being maintained. Much has already been learned from the analysis of past bolt failures, and as the information base increases, so does understanding of the failure mechanisms involved. Documentation and tracking of these failure patterns assist in long-term ground control planning by highlighting problem areas. This system also provides a means by which to identify trends of bolt failures that may be correlated with installation methods, geometry, mining sequence, and other variables. Figure 3-4 presents a graphical representation of rockbolt failures by type. The overall reduction in bolt failures from 1995 to 1996 represented by the graph is primarily a function of area closures.

In addition to tracking the rockbolt failures, a limited rockbolt failure investigation program was implemented. Several borehole camera surveys were performed in boreholes of failed bolts. One failed rockbolt was overcored to observe the condition of the remaining portion of the bolt located above the first clay seam. Observations from this investigation showed corrosion surfaces on the portion of the bolts remaining in the hole and salt creeping or flowing around the bolt shaft. Studies have also been undertaken to address corrosion and loading effects on the premature failure of support system components.

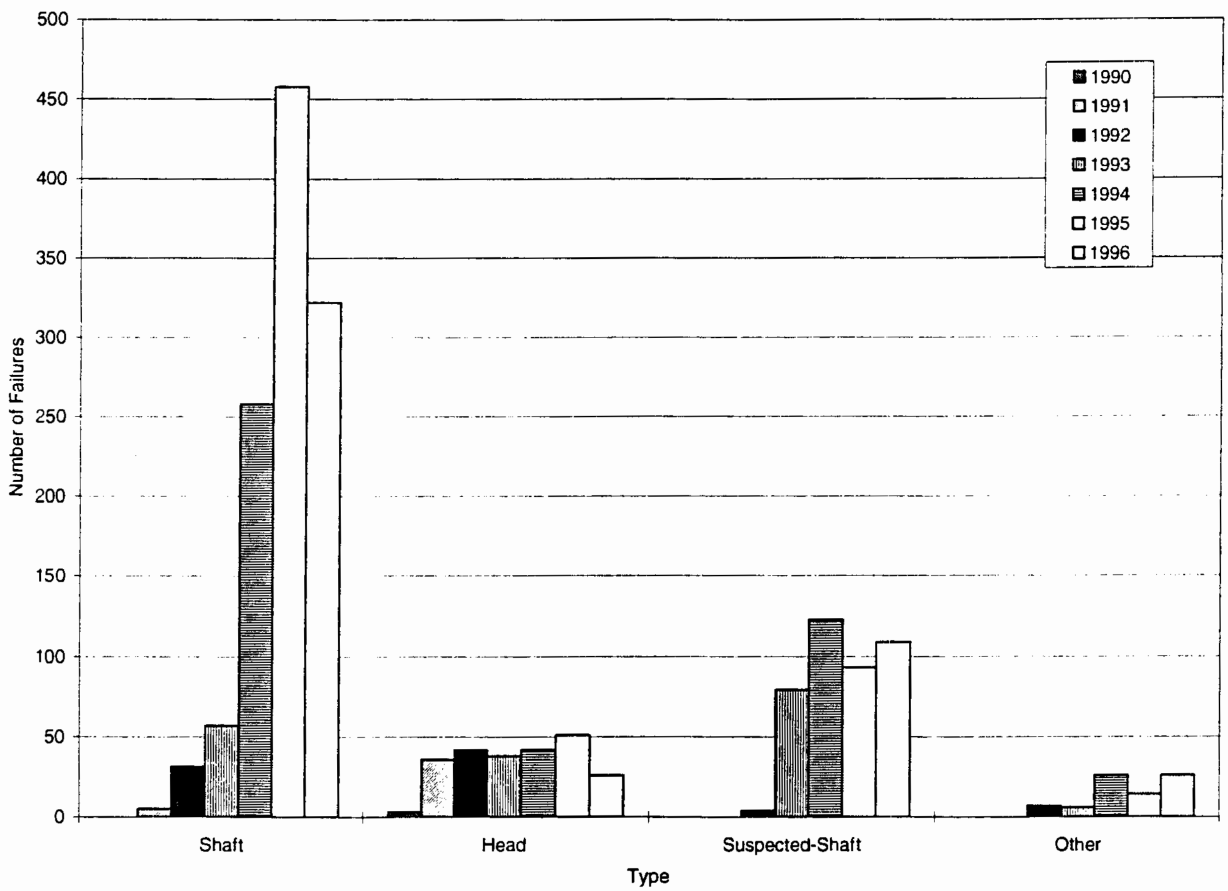

Figure 3-4. Rockbolt Failures by Type

3.3.1 Rockbolt Failure Mechanisms

Extensive testing has been performed on the types of rockbolts and rockbolt material used at WIPP (Lucas, 1984; Deoras, 1992; Chua and Lovato, 1994; and Stoller Corporation, 1995). These tests were conducted to determine the failure mechanisms associated with premature bolt failures and conditions that contributed to those failures.

The most recent testing performed by Stoller Corporation evaluated the effects of corrosion and its relationship to premature failures. The consultant reported that corrosion did not play a major role in the early failure of bolts (e.g., bolts with a life span of five years or less). However, the mechanical-cyclic stress loads the bolts are exposed to while they are under tensile load (that load sometimes being in excess of the bolts yield limit) result in fatigue failure.

A materials evaluation of the mechanical-anchor-type rockbolts and the threaded-bar rockbolts used at WIPP revealed that there was considerable variation in content; for example, carbon content, from bolt to bolt. The variability in content is within design specifications however; each bolt may respond differently, to some degree, under similar loading conditions.

3.3.2 Control of Broken Bolts

In high-use areas and areas where bolt breaking is being observed, Underground Operations provides a secondary attachment of the rockbolts to the roof. A lanyard (safety wire, cable, or chain) is added to the system to prevent the rockbolt or any associated components from falling to the floor should the rockbolt fail. Geotechnical Engineering is assisting Mine Operations in evaluating different techniques to secure broken bolts.

The failure of rockbolts in the underground is a common experience, averaging one to two a day. Because of the safety factor calculated into the ground support design, a substantial number of bolts would have to fail before the integrity of the system would come into question. Therefore, the failure of a rockbolt does not pose a hazard from a ground control standpoint. However, there is a potential hazard associated with personnel or equipment being struck by a falling bolt. Over the years, several different methods of controlling the falling bolts have been employed, with varying degrees of success. Methods used included wire mesh to hold the bolt in place and various lanyards made of wire, chain, or steel cable to catch a broken bolt. The wire mesh method made it difficult or impossible to identify when a bolt had failed. The lanyards appear to work well and make identification and removal of a broken bolt relatively easy. A method currently being tested is to loop a premanufactured stainless steel aircraft cable through the bearing plate or around the rockbolt and secure the cable to the roof with a powder-actuated nail and washer or attach the cable to the welded wire mesh. Simulated field tests of this method have worked satisfactorily. Testing continues to evaluate the most cost-effective and efficient method to control rockbolt falls.

3.4 General Operational Issues and Considerations

Long-term ground control plans are related to the excavation age and operational use of specific areas. When designing a ground control system, the physical access requirements, as well as the geomechanical properties of an area, must be considered. Table 2-1 lists the current use of each ground control zone. Some forms of ground control may not be practical in certain areas, such as shops or offices. In particular, Section 3.5 addresses the ground control issues that must be considered with regard to waste disposal. The projected life of an area is also directly related to its use. Some areas may have to be supported for only a few years; other areas may require support for decades. In areas that require support for long periods of time, for example, the life of the facility, various or multiple support systems will probably be installed during that time.

3.4.1 Excavation Age and Projected Life

Excavation of the underground facility began in 1982, and over 60 percent of the existing openings were completed by the end of 1984. The average age of an opening is 11.5 years, with some openings being over 14 years old. Table 2-1 lists the current age of each ground control area. The age of an excavation is important with respect to ground control because of the amount of deformation that has already occurred and the amount that is anticipated to occur during its projected life.

Some underground openings at WIPP (e.g., the main entries) must remain accessible for up to 50 years. The 50-year life is based on 14 years since excavation, 1 year until receipt of waste, and a 35-year operational life after receipt of waste. With this time frame in mind, support system selection must consider creep-related deformation and support of the beam (if it becomes detached). Beam removal is also an option for long-life areas. The age of an excavation at the time a support system is installed and the age of systems in place are factors that are considered when evaluating the long-term effectiveness of those systems.

Based primarily on its operational use and projections for receipt of waste presented in the WIPP Disposal Decision Plan (DDP), an estimated life was assigned to each zone. The DDP that is included in the Panel 1 Utilization Plan provides a time line to receipt of waste. This time line was used in formulating the projected estimated life of related zones (Westinghouse Electric Corporation, 1994). Three categories, short-term, intermediate, and long-term, were established for this purpose. These projections are an additional tool used in the ground control selection process. The criteria for these designations include the following:

- Short-Term (ST) — A projected life of less than 10 years. This designation includes waste disposal rooms.
- Intermediate (I) — A projected life of 10 to 15 years. Special use areas such as maintenance shops are included here. Shops will be required for the life of the facility, but because of creep-related closure, it is assumed that they may be relocated periodically.
- Long-Term (LT) — A projected life of up to 40 years or the life of the facility. This designation covers all areas critical to the long-term operation of the facility. Shaft stations, main ventilation drifts, and main access and haulage routes fall in this category.

These projections use the excavation date as a start time. If the current use of an area changes or receipt of waste is delayed significantly, designations for specific zones may be adjusted (e.g., a short-term area may change to an intermediate). Areas deactivated are designated as closed and have no projected life. The closed areas could be activated; but this is not anticipated, with the exception of East-140 south of South-2180.

These projections are informal and conditional and are used solely for the purposes set forth in this plan, primarily ground control planning. Table 2-1 lists the projected life of each zone.

3.4.2 Operational Designations

The drifts and alcoves are categorized according to their primary functions which are identified in Table 2-1. The following is a list of operational categories and a brief explanation of how the category is addressed regarding ground control.

- Shops and Offices — Maintenance and fabrication shops exist to support Underground Operations. Office areas are located in various alcoves and crosscuts. Shops and offices should be considered transient. They may be moved as an alternative to maintaining long-term ground control.

routing of ventilation and utility systems. These areas are evaluated on a case-by-case basis.

3.5 Issues Specific to Panel 1 and Future Waste Disposal Panels

Panel 1 has been excavated for several years. Ground control was implemented in the panel in a manner similar to the rest of the facility based on a policy of applying the most appropriate technology to the issue at hand. Occasional ground control beyond visual inspection and scaling may be required for a particular room. During waste handling operations, frequent inspections and assessments will be performed to ensure that room performance is as anticipated, and if not, appropriate actions will be taken. Once waste is emplaced, access to the filled area will no longer be possible. The implication of this is that ground control systems installed at the time of waste emplacement will be designed to support the area until after the panel closure systems are constructed. If, for whatever reason, a roof fall in a panel room filled or partially filled with waste were to be predicted, appropriate actions will be implemented. These actions include the placement of a room/panel closure system.

The schedule for the receipt of waste, both initial waste receipt and rate of receipt, is a crucial parameter in making ground control decisions relative to Panel 1. Because of the age of the panel and the continuing deformation taking place, the timing of waste emplacement will affect the support requirements relative to each room. Figure 3-5 presents the modified Repository Waste Emplacement Schedule. The waste emplacement schedule presented here has been modified from that presented in the *Panel 1 Utilization Plan 1996 Update* (Garcia, 1996) to reflect a 6-month delay in waste receipt (U.S. Department of Energy, 1997a).

Panel 1 also provides an area for testing and evaluation of new ground support systems. These systems have been installed to provide experimental performance data and to provide supplemental support. To the extent that it is practical within the space available, this area may continue to serve as a test zone for new ground control systems.

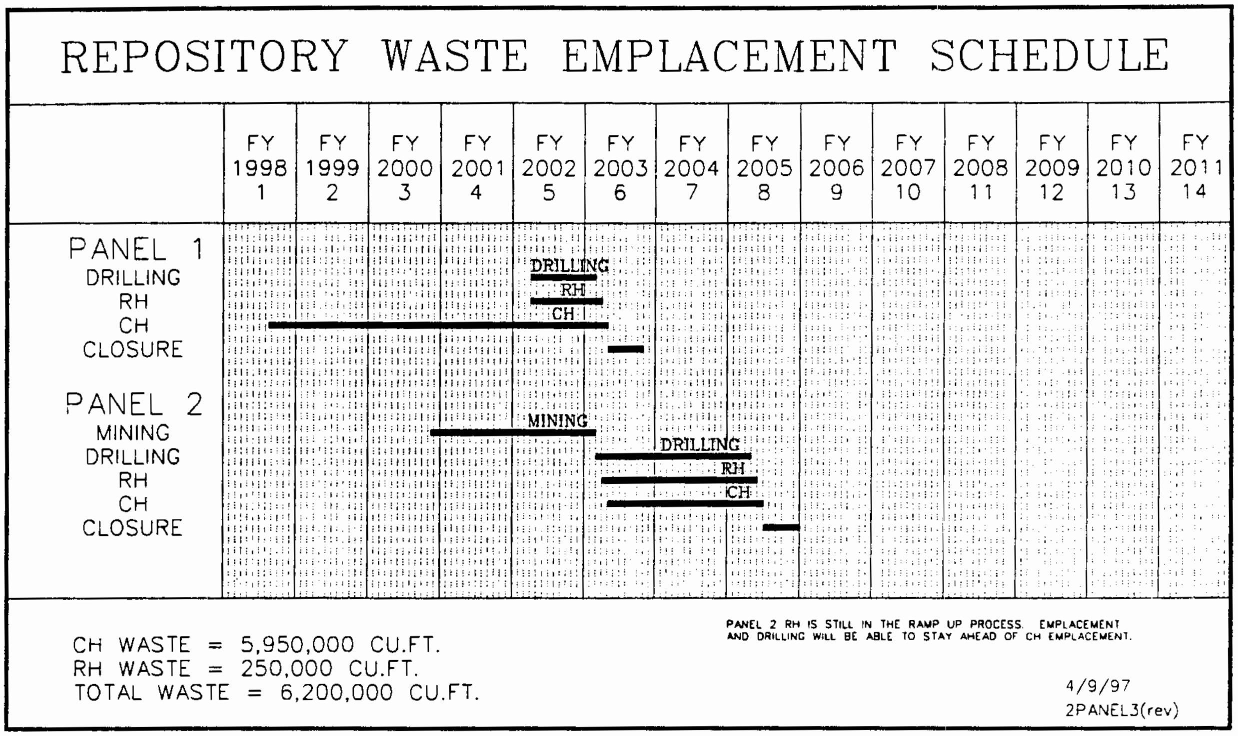

Figure 3-5. Modified Repository Waste Emplacement Schedule

Support projections for specific areas of the panel are being developed based on the schedule presented in Figure 3-5. Deviations from the schedule can affect ground control preparation and other pre-disposal activities in two ways: (1) if the waste receipt schedule is accelerated, there may not be adequate time to install ground support systems as planned, and (2) if the schedule is delayed, the ground control methods planned may have to be supplemented with additional measures to support the new time frame.

4.0 GROUND CONTROL OPTIONS

The objective of each ground control option is to provide safe, geotechnically stable access for personnel and equipment while maintaining disposal capabilities. The options available to meet this objective involve providing internal support (e.g., bolts of various kinds), external support (e.g., cribs), or removing the roof beam. Closure of selected areas is an administrative choice in lieu of ground control options. Restated, these options are support the ground, remove the ground, or close the area.

With respect to supporting the ground, the ground control program has developed an extensive database of WIPP specific information on ground control systems. Monitoring of installed supplemental systems will continue to provide a larger information base for ground control system selection. In addition to *in situ* testing, a expansion rates, installation time with respect to excavation date, offset, and bolt load/elongation properties must be considered in any support design.

External Support Systems

External ground control options rank low when evaluating support systems because (1) there is no evidence at this time that external systems offer substantial performance advantages over internal systems, and (2) external systems are much more intrusive from an operational interference standpoint. The type of external support most often used in the mining industry is cribs. For cribs to be effective, they would need to be extensive, which would severely restrict storage area and operational maneuverability (i.e., it may not be operationally possible to place them where required). If cribs are used sparingly to support specific areas, they may cause stress concentrations and promote further breakup of the roof beam.

4.1.1 Mechanically Anchored (Expansion Shell) Bolts

Historically, the majority of ground control efforts used mechanically anchored bolts, particularly in pattern bolting of the roof. The current and projected use of mechanically anchored rockbolts in the underground is now limited in scope. The majority of currently planned tasks call for the use of resin-anchored threaded-bar bolts as the primary support elements of a system, in conjunction with mechanical-anchor bolts near the ribs to control spalling. Short mechanical-anchor bolts are employed for hanging mesh to control spalling of the ribs and roof. Another use of the mechanical bolts is spot bolting of an area where limited size and specific conditions warrant a small-scale bolting effort. Ground conditions and operational considerations may still require the limited local use of mechanically anchored bolts in the foreseeable future.

4.1.2 Deformed Threaded Rebar

Threaded-bar bolts with a limited-length resin anchor (e.g., 3 feet or 0.9 meter) are used for area pattern bolting as opposed to limited spot bolting. For large areas needing roof support, pattern bolting with No. 7 (7/8-inch or 22-millimeter diameter) or No. 8 (1-inch or 25-millimeter diameter) threaded-bar bolts is the primary support system. Partially resin-anchored threaded-bar bolts provide load-bearing capacity and ductility superior to the mechanically anchored bolts historically used in Panel 1 and elsewhere at WIPP.

The threaded bars are anchored above the first clay seam to provide direct support of the roof beam, and are commonly used in conjunction with welded-wire mesh to contain smaller pieces of rock that may detach from the roof. To provide support for brows, a combination of resin-anchored threaded bar, cable shoes, and cable is typically installed at WIPP.

4.1.3 Yielding Systems

A variety of yielding systems are in place in the underground as small-scale and full-scale test emplacements. Threaded-bar bolts and cable bolts are being used with peripheral yielding components designed to yield with the creep-induced movement of the rock while at the same time providing dead-weight load support in the event of rock detachment. These systems should have a longer effective life with greater integrity through design by yielding to the creep process. Cable bolts also have an application in areas where roof height makes installation of a long rigid rockbolt difficult.

4.1.4 Cable Mesh or Lacing

The threaded-bar bolts may also be incorporated into a supplemental system of cable lacing. This type of support generally involves a grid system of wire-rope run transversely and longitudinally to form a square pattern. The wire ropes are woven under and over each other and supported at selected locations with the threaded-bar bolts. The intent of the cable lacing is to support small portions of detached rock that may not be controlled adequately by the existing threaded-bar bolts.

4.1.5 Room 1, Panel 1, Support System

This type of system provides a high level of confidence for ground control. A layered support structure of welded-wire mesh, expanded metal, channel steel, and point-anchored threaded bar provides intensive support. The system is considered a yielding system because of the ability to manually detension the bolts. If the detensioning process is stopped, the system becomes rigid, non-yielding, and will undergo the same ductile behavior as other rigid systems. Load cells incorporated into each rockbolt provide load monitoring capability. Because of the cost of installation and long-term maintenance associated with this type of system, it does not lend itself to general ground control applications.

4.1.6 Cribs

Cribs have been used to a limited extent in areas currently closed to access. The primary intended function of the cribs is to limit the extent of a roof fall that may occur in areas where continued ground control activities are no longer being performed (i.e., at the perimeter of closed areas).

4.2 Excavation Alternatives

Excavation alternatives with respect to existing openings generally mean complete removal of the roof beam. The removal of the roof beam is not a support system but a mining alternative to ground support. The removal of the beam up to the next competent layer should be considered when adequate support cannot be provided in a cost-effective manner or if removal of the beam will result in a safer working environment. In existing drifts with anticipated long lives, creep closure may ultimately require additional excavation to maintain operational clearance. Field results of the beam removal in the East-140 Drift (the beam was removed from East-140, South-1000 to East-140, South 1950) have shown this to be a viable alternative in areas of advanced beam deterioration. Observations, in the form of displacement measurements and fracture mapping, support the concept of removing the roof beam to enhance stability. Because many of the drifts that require long lives have already been mined, the effect of removing the roof beam well after initial mining has been investigated (U.S. Department of Energy, 1994).

Beam removal activities at the salt shaft station and in the East-140 Drift were performed quite successfully, and the results indicate that the newly created roof is essentially fracture free and geotechnically stable. The activities accomplished several goals and provided for monitoring observations that included the following:

- Documentation of removal techniques that prove that the roadheader can mine through threaded bars, bolts, and cable bolts without major difficulty.
- Mapping of roof-beam fracture patterns that confirmed failure modes and mechanisms.
- Observation and evaluation of in-place ground support as it was exposed, showing the reaction of various components to beam expansion and stratigraphic offset.
- Evaluation of the inherent stability of the fractured beam after support systems were removed, indicated by the fact no roof falls were encountered during mining activity.
- Creation of a competent roof verified by extensometer data and physical observations.

Current extensometer data in the area of the beam removal in the East-140 drift indicate a marked decrease in closure rates following the removal process in comparison to rates before removal. The trends in the data also indicate an apparent stable condition (i.e., the closure rate curve is flat as opposed to increasing). Additionally, physical observations in the area reveal a roof free of fractures or other indications of deterioration. This presents a new drift configuration for this area and provides an opportunity to compare new geotechnical data with data from previous configurations.

4.3 Area Closure

The decision to close an area instead of supporting it involves administrative decisions as opposed to engineering solutions and, therefore, involves less labor and material costs. This option generally applies to areas that have reached the end of their useful life, or that, from an economical and/or safety standpoint, it would more prudent to close than to maintain. Closure of areas of the facility has been exercised in the past (e.g., all areas north of North-780). The option to close select areas of Panel 1 if safety becomes a concern was first formally noted in the *1994 Panel 1 Utilization Plan* and remains viable (Westinghouse Electric Corporation, 1994).

Consideration must also be given to the logistics of anticipated reopening an area. The area of East-140 south of South-2180 will be reopened to service Panels 2 through 4. This area has been closed for several years, and its current condition is unknown. Significant ground control actions and/or excavation activities will be required and are planned before reentry into East-140 south of South-2180.

5.0 GROUND CONTROL DESIGN AND IMPLEMENTATION CRITERIA

Ground control criteria are based on long-term objectives, experience, performance of existing systems, laboratory and *in situ* tests of selected ground control components and/or systems, numerical analysis, and a vast amount of site-specific geotechnical data which have been accumulated since the site was opened. The criteria may be modified to accommodate technological advances, geologic conditions, or operational changes.

5.1 System Design Description Documents

Specific design criteria that were originally established for the WIPP site are documented in the Design Validation Final Report (U.S. Department of Energy, 1986). Some of the design criteria directly or indirectly affect ground control decisions and activities. In 1994 the original Bechtel Corporation design documents were superseded by more detailed Systems Design Description (SDD) documents. The following paragraphs discuss the logic supporting that project decision.

The Design Validation Final Report supported the decision to proceed with Title II construction of the WIPP site. The necessary design information contained in the report was reflected in the Bechtel Design Basis (BDB) (U.S. Department of Energy, 1980; 1982; 1983) which described the specifications to which WIPP was subsequently constructed. To provide a more comprehensive basis upon which to manage and control the configuration of WIPP during operation, SDD documents were developed. The design requirements contained within the individual BDBs are included in the associated SDD. However, in addition to describing the design requirements, the more comprehensive SDDs also provide a very detailed design description. The development and use of the SDDs ensures that the configuration of WIPP is maintained, changed, and documented in accordance with sound engineering practices. The Design Validation Final Report and the BDB as controlling documents were superseded and are now historic records. Current and future engineering efforts, including design modifications, will use the SDDs as the design baseline information documents.

In accordance with the design requirements set forth in the System Design Description, Plant Buildings, Underground Facilities and Equipment, SDD-AUOO (U.S. Department of Energy, 1996b), the design of ground control systems shall provide ground control instrumentation and equipment capable of monitoring ground stability and roof support adequacy. The ground control system shall provide for a concerted and centralized activity with the responsibility to ensure maintenance of safe conditions for personnel and equipment and to provide a continuing assessment of capabilities of the underground openings to allow waste disposal activities.

5.2 Long-Term Support System Design Criteria

Geotechnical data indicate that rockbolt systems have little or no measurable effect on creep closure. The mechanism of creep and the ability of the salt to flow is driven by differential stresses initiated by excavation. The lithostatic stress at the disposal horizon is approximately 2,000 psi (13.8 MPa). When dealing with stresses of this magnitude, it is nearly impossible from an engineering standpoint, and impractical from an economics standpoint, to design and install a mine-wide ground control system that would arrest these forces. Such a system would also reduce the waste isolation performance of the facility (the ability of salt to creep and encapsulate the waste), which is its primary function. Testing is ongoing to evaluate and fine tune performance characteristics of yielding systems. If testing results confirm their adequacy, it is preferable to use a yielding support system that adjusts to the creep, yet still retains the strength to support the deadweight load of a detached mass of salt. The extent of creep-related deformation and the possibility of corrosion effects that may occur over long periods of time present unique design considerations for this yielding system. Design criteria to be considered for a yielding long-term system include the following:

- The support system shall support the deadweight load of the detached roof beam.

- The support system should accommodate vertical movements of the roof.
- The support system should accommodate lateral offset in the roof.
- The support system should be resistant to corrosion effects.
- The yielding component of a yielding support system should be monitorable.
- The support system should be monitorable for component failure.

5.3 Implementation Criteria

One of the more difficult aspects of ground control is determining and evaluating the criteria that indicate when ground control actions should be initiated. The identification of instabilities is critical to maintaining a safe underground environment. Ground control can be expensive and, in some instances, ground control measures can actually have an adverse effect on the *in situ* conditions (e.g., the breakup of a beam associated with installation of rigid bolts). Therefore, it is prudent to be as rigorous as possible in determining when to initiate ground control actions and what those actions should be. The process followed at WIPP includes evaluation of the following three general categories of information:

- Collection and analyses of geomechanical instrumentation data.
- Evaluation of the performance of installed ground support systems.
- Evaluation of physical observations.

Each category is evaluated independently and comparatively to the other categories. With respect to Panel 1, waste emplacement schedules must also be considered for logistic purposes. Criteria for corrective action are continually reevaluated and reassessed based on total performance to date. Actions taken are based on these analyses and the planned use of the excavation.

Support systems are installed to the requirements of Code of Federal Regulations (CFR) 30 CFR 57, Subpart B. Quality Assurance/Quality Control personnel conduct random and as requested checks as each system is installed. In addition, roof-support plans and practices are regularly reviewed and inspected by the Mine Safety and Health Administration and the New Mexico Bureau of Mine Inspection.

6.0 PLANNED AND RECOMMENDED ACTIONS

The fundamentals on which the ground control program at WIPP are based are as follows:

- Ground stability is maintained as long as access is possible.
- Ground control maintenance efforts increase with the age of the openings.
- Ground control plans are specific but flexible.
- Regular ground control maintenance is required.

The approach used in the ground control program at WIPP utilizes experience gained from observation and analysis of salt behavior underground. This experience allows various projections to be made regarding future ground-support requirements. All proposed actions presented in this section are subject to time and budgetary constraints. Some non-safety related items may not be addressed or may be delayed.

In general terms, where reinforcing of existing support is required, a point-anchored threaded-bar bolt pattern with full-load anchor nuts will be used to supplement the existing pattern. In critical areas where cantilevering or fracturing of the beam is observed, a cable lacing system may be used, generally in conjunction with the threaded-bar system. If an opening is projected to be closed to access within a short time, mechanical bolts may be used to reinforce the existing support. The option to use cable bolts in areas where a thick roof beam and a low roof height make installation of long, rigid bolts difficult is also being considered. New excavations will probably be pattern bolted after the initial high creep response has passed (usually 1 to 3 years after excavation, depending on the opening geometry and nearby excavation patterns). Specific plans and layouts will be prepared and will be based on a detailed evaluation of each area.

Planned actions will be implemented in accordance with the general requirements for the control of test activities as described in the Geotechnical and Geoscience Procedure Manual (Westinghouse Electric Corporation, 1991a), and with the Westinghouse Waste Isolation Division quality assurance program description requirements (Westinghouse Electric Corporation, 1991b).

6.1 Near-Term Ground Control Actions

Panel 1 ground control activities will be performed as required to address safety issues and/or waste emplacement schedules. Supplemental ground support, that may include additional pattern bolting and cable lacing, will be incorporated into each room just prior to scheduled waste emplacement for that room. Ground removal actions may also be necessary to reacquire specified opening dimensions. Milling or mining of the floor will be performed to provide adequate opening height and to furnish a smooth working surface for waste emplacement activities. Mining of the floor in Room 7 was completed in 1997. Supplemental bolting along the access routes to the panel rooms, which include the Waste Shaft Station, the East-140 Drift, and the South-1950 Drift will be performed as required.

The threaded-bar bolts in Room 1 are being manually detensioned approximately once a month based on bolt loading. Results of testing performed on threaded-bar bolts installed in Room 2 indicate that the addition of yielding Titan Load Indicators can substantially increase the time between detensioning events. Current plans call for the addition of these load indicators to all of the threaded-bar bolts in Room 1. As a yielding system the threaded-bar bolts in Room 1 are limited by the length of tail remaining on an individual bolt. The current intent is to allow the bolts to load and yield to failure when they run out of tail. Consistent with all areas of the facility, failed bolts will be replaced.

Current testing plans include installation of a pattern of yielding cable. This installation will provide for a full-scale pattern evaluation of the cable bolt technology. An element of the evaluation process involves cooperation with commercial mines in the development of these technologies.

6.2 Long-Term Plans and Options for Panel 1

Panel 1 continues to support a variety of regulatory compliance activities that are scheduled to be completed before first waste receipt. Keeping Panel 1 operationally ready for waste receipt supports the requirements of the RCRA permit application. Geotechnical, operational, and other performance information derived from Panel 1 is also used to demonstrate compliance in regulatory documents required for starting disposal operations, in particular, the RCRA Part B Permit Application and the Compliance Certification Application.

This section provides options for panel usage and the ground control alternatives required to implement those options. Evaluation of specific areas and recommendations for remedial ground control procedures must be made in a time frame that allows for implementation of those procedures prior to waste emplacement. Under all options, general maintenance activities, such as scaling down small pieces of rock and replacing identified broken bolts, would continue in all accessible areas. The identified options are:

- Use all of Panel 1.
- Receive first waste in Panel 1 and use as much of the panel as possible.
- Receive first waste in Panel 1 and move to Panel 2 as soon as possible.

- Close Panel 1 and begin initial waste emplacement in Panel 2.

In the case of several of the options and alternatives, significant overlap exists. For example, the current plan, consistent with the *1994 Panel 1 Utilization Plan* (Westinghouse Electric Corporation, 1994) and the subsequent 1996 update of that plan (Garcia, 1996) is to receive waste in Panel 1 and use as much of the area as possible. If waste is received in 1998 and emplacement proceeds expeditiously, it is probable that all of the panel can be used to emplace waste. However, if delays are experienced in waste receipt or in the emplacement sequence, portions of the panel may not be used or substantial efforts may be necessary to maintain the required ground control.

6.2.1 Use All of Panel 1

The waste receipt schedule as discussed in Section 3.5 is a critical parameter when planning to use all of Panel 1. The modified Repository Waste Emplacement Schedule as presented in Figure 3-5 will be used for the following alternative discussions. Based on this schedule, it is reasonable to expect at this time that with the use of proven ground control techniques, all of Panel 1 can be used for waste disposal. However, if there is a significant delay in the waste emplacement schedule, the preference of alternatives may change. For example, a 5-year delay in the schedule may make beam removal options more attractive.

<u>Alternative 1</u> — Install supplemental support of cable lacing in conjunction with rebolting and mining down of fractured roof beams as required.

Under this alternative, broken bolts in active support systems will be replaced as they are identified. Current plans call for installation of supplemental ground support in each room prior to waste emplacement. Because ground control activities cannot be performed in areas where waste has been emplaced, it is desirable to install the supplemental systems as near to the time of waste emplacement as possible. Given the planned waste receipt rates, this will ensure that the system will remain effective through the waste emplacement period for the area. A preferred system at this time would consist of a combination of threaded-bar bolts for primary support, mechanical-anchor bolts for supporting smaller pieces of rock near the ribs as required, welded-wire mesh throughout to contain small rock, and a square pattern of 5/8-inch (15.87-millimeter) steel-cable lacing to support larger pieces of rock that may hang or detach.

Sections of rock may be scaled down or, in more extreme cases, portions of the roof beam may be excavated or mined before the supplemental system is installed. Mining of the roof beam is the most time-consuming component of this alternative. Adequate time must be allowed to accomplish this task, if required. If the entire beam is removed throughout the room, the mining sequence will take approximately 6 months, based on East-140 roof-beam mining rates (single shift). If beam removal is employed, backfilling of the floor will be required to maintain the as-designed and permitted size of the disposal rooms. Depending on the degree of beam removal planned, several months may be required for each section of beam to be removed. For example, if a large section of the beam were to be removed in Room 7, the first room scheduled to receive waste, those activities would need to be initiated as soon as possible in 1997 to meet the mid-1998 waste receipt schedule. On the other hand, if the only room anticipated for beam removal activities was Room 1, those actions could be initiated sometime after initial receipt of waste.

Alternative 2 — Install supplemental support of cable lacing in conjunction with rebolting and installation of external support as required.

The rebolting and cable lacing system will be the same or similar for this alternative as that for Alternative 1. Installation of external support, such as cribs, could be performed before or after the internal support was installed. The external support will be placed in areas of concern, such as along a rib where the roof had extensive low-angle fracturing or in the center of a room where closure rates may be greater. External support will decrease the disposal capacity of the room, and consideration must be given to its possible interference with waste handling operations.

Alternative 3 — Mine the roof in the entire panel.

To exercise this option under the present waste receipt schedule would require that beam removal activities begin as soon as possible in 1997. It would be desirable to have two or three rooms completed prior to initial waste receipt in order to be assured of staying ahead of the waste disposal operations. The most likely scenario for this alternative to be considered viable would be in the case of a significant delay in the initial receipt of waste (e.g., 5 years).

6.2.2 Receive the First Waste in Panel 1 and Use as Much of the Panel as Possible

Alternative 1 — Supplemental support of cable lacing in conjunction with rebolting and closing individual rooms only as required.

This option is the current course being followed and is consistent with plans established in the *1994 Panel 1 Utilization Plan* (Westinghouse Electric Corporation, 1994). This plan does not exclude the alternative to use all of the panel, but includes the option to close a room or area if necessary.

Following this plan, broken bolts will be replaced as they are identified. Supplemental support will be installed in the area chosen for initial emplacement as near to the time of waste receipt as possible. As disposal operations progress, the viability of using rooms will be assessed primarily from a safety standpoint, but also with economic and operational considerations in mind. If it is necessary, a room or several rooms could be closed. Factors other than the stability of the rooms that may affect this decision include the availability of Panel 2, the anticipated volume of waste to be received, and the rate of waste receipt and emplacement.

Using the modified waste emplacement schedule as a guide and taking into account the current age and condition of the Panel 1 rooms, a rough prediction of which rooms may be at risk can be made. Rooms 1, 2, and 3 are 1 to 2 years older than Rooms 4 through 7. Additionally, the sequence of waste emplacement begins with Room 7 and progresses to Room 1 over a period of approximately 4.5 years. This means that when waste is emplaced in Room 1, it will be approximately 6 years older than Room 7 was when waste was emplaced there. It follows that the rock deformation associated with this 6-year period will increase the probability of Room 1 experiencing unacceptable ground conditions. Hence, Room 1 would be the most likely room to be closed and abandoned. Because the rooms were excavated generally in the opposite order of which they will be used, all things being equal, it seems reasonable to assume that Room 2 would be the next logical choice for abandonment and so on down to Room 7. However, all things are not necessarily equal. At the present time, Room 3 is in better condition than Room 4. This means, for example, it is possible that Room 4 could be abandoned and Room 3 used.

6.2.3 Receive the First Waste in Panel 1 and Move to Panel 2 as Soon as Possible

<u>Alternative 1</u> — Supplemental support of cable lacing in conjunction with rebolting and move to Panel 2 as soon as it is ready.

Installation procedures for supplemental ground support under this option are identical to previous alternatives. As much of Panel 1 would be used as required until Panel 2 was ready for disposal operations. Several variables come into play under this alternative that will affect which rooms of the panel may or may not be used. The key variable will be the anticipated completion time for Panel 2. Assuming the completion date for Panel 2 and the rate of waste receipt is known, a fairly accurate estimate can be made of the disposal space required in Panel 1, allowing the luxury of selecting only the best rooms for use. If, for example, Room 7 was nearly filled with waste and Panel 2 was scheduled for completion in 4 months, and knowing that 4 months' worth of waste would not fill an entire room, any of the remaining rooms could be selected. The room used would probably be the one determined to be in the best condition.

6.2.4 Close All of Panel 1 and Begin Initial Waste Emplacement in Panel 2

No further ground control activities in Panel 1 would be required under this option. Pertinent factors in this decision would be the consequences from a regulatory, operations, and performance assessment standpoint of closing Panel 1. Some of these consequences are discussed in the *1994 Panel 1 Utilization Plan* (Westinghouse Electric Corporation, 1994).

6.3 New Waste-Emplacement Panels

Prior to waste emplacement in any specific area or room, the plans for Panels 2 through 8 are to spot bolt with short, mechanically-anchored bolts only as necessary, if spalls or loose ground are encountered during and after the mining process. Mesh may be used in conjunction with these bolts to secure any loose ground encountered during normal inspection processes. These bolts would not penetrate through to the next clay/anhydrite interface and would be anchored within the beam formed by the mine roof and the clay clay/anhydrite interface above. This is the primary or initial support currently planned for use in Panels 2 through 8.

If ground conditions require, pattern bolting may commence at any time after excavation. However, based on experience with the SPDV rooms and the rooms in Panel 1, pattern bolting is not expected to be required until 2 to 5 years after excavation. The system judged best, which is available at the time a need for pattern bolting is identified, will be used in Panels 2 through 8. Because yielding systems are still under evaluation, current plans call for the use of Grade 60 threaded bars of at least 7/8 in. (22-millimeter) diameter installed on a maximum 5 foot by 5 foot (1.5 meter by 1.5 meter) pattern in the center half of the room. The bars would be resin anchored above the first clay/anhydrite interface. Four or six-foot-long (1.2 or 1.8-meter-long) mechanical-anchor bolts may be used near the ribs.

6.4 Geotechnical Monitoring

The geotechnical monitoring program, which includes visual and instrument monitoring, will be expanded as necessary to ensure adequate and appropriate coverage of all accessible areas of the facility. The removal of the roof beam in the East-140 Drift represents a new opening configuration for that area. Monitoring of the new roof beam will provide data to evaluate performance characteristics of this configuration.

Panel 1 will continue to receive a high degree of scrutiny regarding ground stability and support-system performance. The floor excavation performed in Room 7 produced a new room configuration, and monitoring should be increased in the area to evaluate the geotechnical response. All issues associated with the use of Panel 1 will be reviewed annually at a minimum.

The minimum instrumentation planned for panels 2 through 8 is one borehole extensometer installed in the roof at the center of each disposal room. The roof extensometers will monitor the expansion of the immediate roof beam and possible bed separations along clay seams. Additional instrumentation may be installed as conditions warrant.

The Ground Control Monitoring System (GCMS) is a computerized process-control and real-time data acquisition system. The system is typically used to control such things as pumps, fans, and alarms. The primary use of the system at WIPP is for geotechnical data acquisition that requires the ability to monitor slow deformation rates and detect very small movements. The system has been modified and upgraded to increase its resolution and its ability to interface with a wide variety of geotechnical instruments. The system is presently monitoring rockbolt load cells, extensometers, strain gages, crack meters, and convergence meters. It is planned that eventually most of the geotechnical instruments in the underground will be read with the GCMS.

Remote polling of the geomechanical instrumentation is performed at least once every month. This frequency may be increased to accommodate any changes that may develop.

6.5 Numerical Modeling

Numerical modeling has proven to be a valuable tool in predictive and comparative analyses of excavations and excavation effects. This technology is changing and improving as computer technology evolves. For example, three-dimensional analyses are being used to model excavations at WIPP. Detailed information and results of some of the numerical modeling being performed at the site can be found in the *Geotechnical Analysis Report* (U.S. Department of Energy, 1996a).

6.6 Ground Control System Testing Program

Testing of various ground support components and systems has been an ongoing action at WIPP for several years. Monitoring of selected components of small-scale and large-scale *in situ* tests will continue to be performed. Monitoring of the support system performance provides an assessment of the manner in which the support is controlling roof movements. Evaluation of yielding systems will continue to be of particular interest. The testing and evaluation of rockbolt restraint devices will also continue.

Geomechanical instrumentation will be installed in conjunction with ground control system instrumentation so data comparisons can be made between factors such as roof beam expansion, bolt load, and bolt strain. An objective is to ascertain the degree to which a support system can affect rock movement.

As new technologies are developed or identified, they will be evaluated for their applicability to WIPP. Laboratory and *in situ* testing will be performed on these systems if warranted.

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APPENDIX A

SUMMARY OF GROUND CONTROL EVENTS AND REMEDIAL ACTIONS

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A.0 GROUND CONTROL HISTORY AND REMEDIAL ACTION

A.1 Ground Control History

Ground control issues have been addressed since underground excavation began. Excluding issues associated with the shafts, the first matters of concern were minor spalls or isolated areas with thin slabs (about 6 inches or 0.15-meter or less). These areas were mined out if possible. If the excavation tolerances of an area (primarily in experimental areas) made it impractical to mine or scale the zone or if the slab was too thick, the affected area was spot bolted to address the immediate safety concern. Most spot bolting was performed with 2-foot-long (0.61-meter-long) mechanical anchor rockbolts.

When excavations at WIPP were new, they were relatively stable and did not require a great deal of maintenance. As the openings aged, fracturing began to occur at the corners of pillars. These fractures were monitored and material was scaled off if it presented a safety concern. The current procedure for corners is to miter, bolt, and mesh all of the pillar corners.

In 1985, while drilling boreholes in the floor of Site and Preliminary Design Validation (SPDV) Room 3, an extensive fracture system associated with the anhydrite layer, Marker Bed 139 (MB139), was observed. Separations at the salt/anhydrite interface as well as fractures within the nearly 3-foot-thick (0.9-meter-thick) anhydrite layer itself were evident. In May of 1986 a program consisting of boreholes drilled into the floor and roof throughout the facility was initiated to investigate and quantify the scope of fracture and offset development as a result of excavation. A historical summary of excavation effects can be found in the *Geotechnical Analysis Report* (U.S. Department of Energy, 1996a).

From September 1987 to February 1988, the roof beam below clay G at the Salt Handling Shaft station was removed with a scaling machine. This action was taken because of observed displacements, separations, and fractures in boreholes in the shaft station roof.

SPDV Rooms 1 and 2 were closed and barricaded in April and May of 1989, respectively, to allow for safe monitoring of deteriorating ground conditions. This safety action was prompted by monitoring data, fracture mapping, and confirmation by drilling of an extensive continuous fracture system in the roof of these rooms. Ground control in these rooms was limited to mechanical anchor rockbolts 2 feet (0.6 meter) in length and chain-link mesh to control spalling. On February 4, 1991, an anticipated roof fall estimated at approximately 700 tons (636 metric tons) occurred in SPDV Room 1. The fallen slab had a triangular cross section, covered an area 33 feet (10.1 meters) in width by 180 feet (54.9 meters) in length, and was about 7 feet (2.1 meters) thick at its apex. A roof fall occurred in SPDV Room 2 in June of 1994. This roof fall was comparable in size to the one in SPDV Room 1. As with Room 1, the fall was anticipated and predicted which allowed for the event to be videotaped as it occurred.

The A and B series test rooms also experienced roof control problems. To simulate high-level waste conditions these rooms were heated. The heat accelerated closure rates. Because of deteriorating conditions, Room B was pattern bolted. However, rockbolting of the A rooms was minimal (spot bolting only). The experimental nature of the rooms and the massive amount of instrumentation they contained precluded installation of significant ground control mechanisms that could have affected geomechanical data results. Access to the rooms was controlled, and eventually the rooms were closed. The first roof fall at WIPP occurred in Room A2 on June 19, 1990. Since that time, there have been roof falls in all of the A rooms. The roof falls consisted of slabs approximately 18 inches (0.5 meter) thick. No ground falls are known to have taken place in Room B. In each case where a ground fall has occurred at WIPP, no ground control measures had been implemented to prevent them. No ground falls have occurred where beam control systems have been implemented.

During 1989 and 1990, the roof in most of the underground openings were pattern bolted with 10-foot-long (3.0-meter-long), ¾-inch-diameter (19-millimeter-diameter) mechanical anchor rockbolts. This initial pattern bolting was essentially preventive maintenance, i.e., bolts were installed on a mine-wide basis to preempt ground stability problems. Since that time, a variety of ground control actions were implemented to address specific areas on a case-by-case basis, and a comprehensive ground control program was developed. Through this program, alternative types of ground control have been tested, installed, and evaluated. There is now a greater choice of proven options available to the ground control engineers for addressing the different types of ground control issues encountered. Because of the extent and complexity of the ground control actions initiated under this program, remedial ground control actions implemented subsequent to 1990 are presented in greater detail in the following sections.

A.2 Remedial Ground Control Actions Implemented to Date

All normally accessible areas of the underground, except the South-90 electrical substation area, are currently rockbolted. However, in some areas, such as the East-300 shop, the bolts do not penetrate the first clay seam and are only intended to support the mesh installed to control spalling. Early in the life of the facility, spot bolting was used to address areas of drummy or spalling ground that could not be scaled. Most of this spot bolting was done with 2-foot (0.6-meter) bolts. Beginning in 1989, the entire facility was pattern bolted with mechanical-anchor rockbolts. Bolts 10 feet in length (3.0 meter) predominate, although some areas have been bolted with 5-foot (1.5-meter), 6-foot (1.8-meter), or 8-foot (2.4-meter) bolts. Within the mechanical rockbolt systems, a 5-foot by 5-foot (1.5-meter by 1.5-meter) offset pattern (5-foot by 2.5-foot or 1.5-meter by 0.8-meter triangular) is the most common in the WIPP underground.

Because of limitations of mechanical-anchor rockbolts, more recent support system designs have focused on alternative types of rockbolts, primarily resin-anchored threaded bar. Other systems, such as cable bolts and yielding systems, are being tested and evaluated. In addition to using support systems to address ground control problems, excavation of the roof beam in a 950-foot (290-meter) section of the East-140 Drift was performed and the northern portion of the facility was closed to access eliminating the need for future ground control actions in the area. This section of the report presents an overview of ground control activities that have been initiated to supplement the mechanical-anchor rockbolt systems and to remediate areas of concern.

A.3 Ground Support Systems

A.3.1 Panel 1

Rockbolt support was installed in Panel 1 in 1988 using a rockbolt design based on the requirements for the operations demonstration program then planned. The original plan consisted of the storage of drums of contact-handled transuranic waste in rooms for a period of 5 years. During this time and immediately following, the rooms were to be inaccessible, but the option to enter was to be maintained so that the waste could be retrieved if required. To assist with the possible reentry and to enhance stability, mechanically anchored rockbolts were installed. Ten-foot-long (3.0-meter-long) rockbolts were installed in Rooms 1 through 6, and 6-foot (1.8-meter) rockbolts were installed in Room 7, South-1600, and South-1950.

In 1991, a supplementary roof support system was designed and installed in Room 1 to facilitate a planned bin-scale test program. A detailed description of the supplementary system is presented in the *Waste Isolation Pilot Plant Supplementary Roof Support System Underground Storage Area Room 1, Panel 1* (U.S. Department of Energy, 1991b). Subsequently, additional ground support was installed, or installation is in progress, in all of the Panel 1 rooms and drifts with the exception to date of parts of Rooms 1 and 2. The roof-support history of Panel 1 is important because information on the age of the openings and when ground support was installed is vital to making predictions about future ground support requirements. A summary of additional support systems and year of installation in Panel 1 follows:

1991 — The support system referenced above was installed in Room 1.

1992 — A variation of the Room 1 system was installed in parts of Room 2. Specialized Titan Load Indicators were installed on all of the threaded-bar emplacements in Room 2 in 1996. The indicators, installed to provide yield in the system, have allowed the manual detensioning frequency to be decreased from approximately once a month to approximately once a year.

1994 — Room 7 was rebolted with 13-foot-long (4-meter-long) No. 7 threaded bar with full-load nuts.

The South-1600 Drift was rebolted with 13-foot-long (4-meter-long) No. 7 threaded bar with full-load nuts.

The north half of Room 4 was rebolted with 13-foot-long (4-meter-long) No. 7 threaded bar with slip nuts. The slip nuts are being monitored, and a pattern has developed revealing considerable movement in some areas and virtually no movement in others. In specific areas there has been up to 8 slips per bolt representing approximately 4 inches (0.1-meter) of movement (at least 3 bolts have had 8 slips). In other areas there have been no slips to date (the latest information indicates 63 bolts have had no slips).

Room 5 was rebolted with 12-foot-long (3.7-meter-long) No. 7 threaded bar with full-load nuts.

1995 — The south half of Room 4 was rebolted with 12-foot-long (3.7-meter-long) No. 7 threaded bar with full-load nuts.

Room 6 was rebolted with 12-foot-long (3.7-meter-long) No. 7 threaded bar with full-load nuts.

1996 — Room 3 was rebolted with 13-foot-long (4-meter-long) No. 7 threaded bar with full-load nuts.

1997 — South-1950 was rebolted with 13-foot-long (4-meter-long) No. 7 threaded bar with full-load nuts.

The current bolting process and pattern being employed in the panel consists of using limited-length resin anchored threaded-bar bolts in the drift center where offsetting effects are less in the short term, and where they provide the greatest amount of support in the case of a detaching wedge failure mode. The pattern of threaded-bar bolts is designed to support either a wedged shaped section of rock or the full rectangular cross section. Near the room ribs, short mechanical bolts are typically used.

A.3.2 East-140 Drift

<u>North-460 to North-780</u>

Several arrays of yielding cable bolts are installed in this area. This is considered a full-scale emplacement/experiment. Nine arrays of bolts are (or were) installed, with each successive array (north to south) having a designed yield 5,000 pounds (2,268 kilograms) higher then the previous array. The northernmost row of cable bolts have a designed yield of approximately 20,000 pounds (10,000 kilograms), while the southernmost array has a designed yield of approximately 60,000 pounds (30,000-kilograms).

<u>North-170 to North-460</u>

A 5-foot by 4-foot (1.5-meter by 1.2-meter) square pattern of rockbolts was installed in this area. The pattern consisted of 13-foot-long (4-meter-long) threaded-bar bolts with full-load nuts emplaced in 1 3/8-inch (4-centimeter) diameter boreholes.

length, the width of the drift, and approximately 7-feet thick (2.1-meters) (up to the first clay seam) was removed.

The beam removal operation was begun using a Fletcher mechanical scaler. However, even though the rock was somewhat fractured, the rock proved to be very difficult to remove with the scaling machine. Partway through the operation, as the ground became less fractured, a Dosco roadheader machine replaced the scaler and removed the remaining portion of the beam. Threaded-bar bolts and cable straps are used to provide support to the newly created brow.

A.4.2 East-140 Drift — South (Access to Disposal Panels)

In 1994, the area of the East-140 Drift from South-1300 to South-1950 was identified as requiring supplemental work. A system of threaded-bar bolts and wire-rope pairs was installed in select locations to provide additional support. Because of the size and age of the drift, deterioration continued. Removal of the roof beam to the first clay seam in the portion of the drift between South-1300 and South-1600 was proposed. The proposed activities were approved, and removal of the roof beam for that section of the drift was completed in December 1995. The results of the beam removal were very positive. There were no roof falls ahead of the mining machine even though ground support was removed before excavation of the beam was initiated. The remaining upper beam is in excellent condition from a fracture standpoint and, unlike initial mining, shows no discernible geomechanical response to the mining.

Based on these positive results, the scope of the beam removal operations in the East-140 Drift was expanded. The beam was removed from the South-1600 intersection to the north side of the South-1950 intersection, and from South-1000 to South-1300. Following beam removal in these areas, a preventive maintenance measure of installing mechanical-anchor rockbolts that do not penetrate the roof beam and chain link mesh at the rib roof intersection was employed. The roof beam is now completely removed in the East-140 drift from South-1000 to South 1950. No further beam removal is presently planned in this drift.

A.5 Area Closure

All areas north of North-780 are now closed to access. Room Q is also closed to access, as are the alcoves located north of Panel 1. It is not anticipated that any further ground control activities will take place in these areas. The East-140 Drift south of South-2180 is closed at this time, but this area will eventually be opened and rehabilitated for waste emplacement operations in Panels 2 through 4.