# Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

## Appendix MON

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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# Preclosure and Postclosure (Long-Term) Monitoring Plan

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# FIGURES

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# ACRONYMS

| | |
|---|---|
| BEAR | Backfill Engineering Analysis Report |
| C&C | Consultation and Cooperation |
| CFR | Code of Federal Regulations |
| DOE | U.S. Department of Energy |
| DOI | U.S. Department of the Interior |
| EPA | U.S. Environmental Protection Agency |
| FEIS | Final Environmental Impact Statement |
| FSAR | Final Safety Analysis Report |
| NGS | National Geodetic Survey |
| NMED | New Mexico Environment Department |
| NQA | nuclear quality assurance |
| QA | quality assurance |
| RCRA | Resource Conservation and Recovery Act |
| SNL | Sandia National Laboratories |
| SPDV | Site and Preliminary Design Validation |
| TRU | transuranic |
| VOC | volatile organic compounds |
| WEC | Westinghouse Electric Corporation |
| WIPP | Waste Isolation Pilot Plant |
| WQSP | Water Quality Sampling Program |

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# APPENDIX MON

This report details the techniques and design descriptions of components and systems which will be used in implementation of the preclosure and postclosure (long-term) monitoring plan for the Waste Isolation Pilot Plant (WIPP) repository. The regulatory criteria which drive preclosure and postclosure monitoring of the facility and the rationale for the engineered systems that will be used for monitoring are discussed. This report describes both the preclosure and postclosure monitoring plans.

## MON.1 Purpose

The purpose of this report is to discuss the preclosure and postclosure (long-term) monitoring programs that will be used to measure the WIPP-related significant and monitorable parameters that have been screened by summarizing the regulatory requirements (Title 40 of the Code of Federal Regulations [CFR] § 191.14(b) and the criteria at 40 CFR § 194.42). The five screening criteria that were applied to the parameters individually are

- Addresses significant disposal system parameters,
- Addresses an important disposal system concern,
- Obtains meaningful data in a short time period,
- Does not violate disposal system integrity, and
- Complements Resource Conservation and Recovery Act (RCRA) programs.

The report also identifies the use of subsidence monitoring as the focus for postclosure monitoring in addition to the screened parameters that will form the basis for preclosure monitoring. In describing the postclosure monitoring program, the report also provides an analysis of geophysical techniques that may have possible applicability to remote monitoring of repository performance subsequent to closure.

## MON.2 Scope

The U.S. Department of Energy (DOE) has developed a number of separate monitoring programs to address various environmental, health, safety, and other applicable regulatory requirements. Within these programs, monitoring and measurement activities include the determination of values that are directly and indirectly related to parameters that have survived a screening process which includes the criteria described above. These ongoing programs include a geomechanical monitoring program, a groundwater monitoring program, an environmental monitoring program, a volatile organic compound (VOC) monitoring program, and a subsidence monitoring program. This appendix identifies discrete programs that address monitoring for each of the parameters which survived the screening process, as well as subsidence monitoring.

This appendix describes in detail a postclosure monitoring program built around subsidence monitoring for evaluating long-term repository performance. The postclosure monitoring description includes defining the requirements and developing specifications for the postclosure monitoring system. This will also include the development of testing, quality assurance (QA), and quality control guidelines for the postclosure monitoring program.

Within the subsidence monitoring program description, a discussion of other geophysical techniques addresses technologies that may be used to enhance the technical interpretations resulting from subsidence data in the event that some data are not within the expected range. The known limitations of these technologies in remotely monitoring the repository performance are also described.

## MON.3 Regulatory Background

The WIPP is regulated by the U.S. Environmental Protection Agency (EPA) and the state of New Mexico Environment Department (NMED). In addition, the DOE has entered into an agreement with the state of New Mexico for consultation and cooperation regarding the WIPP. Prior to initiating disposal operations, a hazardous waste permit will be granted by the NMED as required by the RCRA regulations. Also, the EPA is authorized to certify that the WIPP is in compliance with the provisions of 40 CFR Part 191. In February 1996, the EPA promulgated Title 40 CFR Part 194, entitled *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR 191 Disposal Regulations* (EPA 1996a).

As a result of the 40 CFR Part 194 standards governing certification of the WIPP, plans for monitoring the repository during waste emplacement (preclosure) and for the postclosure (long-term) are required. Other requirements imposed on postclosure monitoring are associated with the Agreement of Consultation and Cooperation (C&C) between the state of New Mexico and the DOE (DOE 1981). This agreement details specific postclosure environmental monitoring requirements.

### *MON.3.1 40 CFR § 191.14 EPA Regulation*

The regulations found in 40 CFR Part 191 outline the requirements for the WIPP repository. 40 CFR § 191.14(b) states:

> Disposal systems shall be monitored after disposal to detect substantial and detrimental deviation from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

The regulation states in 40 CFR § 191.14(a),

> Active institutional controls over the disposal sites should be maintained for as long a period of time as practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active controls for more than 100 years after disposal.

The regulation defines as an element of active institutional control, "monitoring parameters related to disposal system performance."

The following list summarizes 40 CFR Part 191 regulations relating to postclosure monitoring.

- The disposal site shall be monitored after disposal to detect substantial and detrimental deviations from expected performance.
- The monitoring techniques used must not jeopardize waste isolation.
- Monitoring will continue as long as practicable and/or until no significant concerns are to be addressed.

### *MON.3.2 40 CFR § 194.42 EPA Regulation*

Title 40 CFR § 194.42 describes the EPA's monitoring criteria that the EPA will use in determining whether or not the requirements which must be addressed by the DOE (the Department in the regulation) have been achieved. These specific criteria are

> (a) The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for preclosure and postclosure monitoring required pursuant to paragraphs (c) and (d) of this section. The disposal system parameters analyzed shall include, at a minimum:
>
> (1) Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;
>
> (2) Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room;
>
> (3) Initiation or displacement of major brittle deformation features in the roof or surrounding rock;
>
> (4) Ground water flow and other effects of human intrusion in the vicinity of the disposal system;
>
> (5) Brine quantity, flux, composition, and spatial distribution;

(6) Gas quantity and composition; and

(7) Temperature distribution.

(b) For all disposal system parameters analyzed pursuant to paragraph (a) of this section, any compliance application shall document and substantiate the decision not to monitor a particular disposal system parameter because that parameter is considered to be insignificant to the containment of waste in the disposal system or to the verification of predictions about the future performance of the disposal system.

(c) Preclosure monitoring. To the extent practicable, preclosure monitoring shall be conducted of significant disposal system parameter(s) as identified by the analysis conducted pursuant to paragraph (a) of this section. A disposal system parameter shall be considered significant if it affects the system's ability to contain waste or the ability to verify predictions about the future performance of the disposal system. Such monitoring shall begin as soon as practicable; however, in no case shall waste be emplaced in the disposal system prior to the implementation of preclosure monitoring. Preclosure monitoring shall end at the time at which the shafts of the disposal system are backfilled and sealed.

(d) Postclosure monitoring. The disposal system shall, to the extent practicable, be monitored as soon as practicable after the shafts of the disposal system are backfilled and sealed to detect substantial and detrimental deviations from expected performance and shall end when the Department can demonstrate to the satisfaction of the Administrator that there are no significant concerns to be addressed by further monitoring. Postclosure monitoring shall be complementary to monitoring required pursuant to applicable federal hazardous waste regulations at part 264, 265, 268, and 270 of this chapter and shall be conducted with techniques that do not jeopardize the containment of waste in the disposal system.

(e) Any compliance application shall include detailed preclosure and postclosure monitoring plans for monitoring the performance of the disposal system. At a minimum, such plans shall:

(1) Identify the parameters that will be monitored and how baseline values will be determined;

(2) Indicate how each parameter will be used to evaluate any deviations from the expected performance of the disposal system; and

(3) Discuss the length of time over which each parameter will be monitored to detect deviations from expected performance.

### *MON.3.3 40 CFR Part 264 Groundwater Monitoring Regulations*

Previous geological exploration and testing have mapped the geologic strata above and below the repository. Two minor water bearing units are in the Rustler Formation approximately 540 to 850 feet (165 to 260 meters) below ground level. The water quality of these units is classified as poor. A small number of exploratory boreholes and hydrocarbon exploration wells in the vicinity of the WIPP site have documented encounters of isolated pressurized brine reservoirs in the Castile Formation, which is approximately 2,825 to 4,075 feet (860 to 1,242 meters) below ground level at the WIPP.

Typically, the RCRA regulations require groundwater monitoring in the uppermost aquifer located directly below a hazardous waste management unit. The EPA allows this requirement to be waived if it can be proven that the hazardous material will not migrate past specified boundaries in excess of health-based limits and that monitoring will not be productive in determining compliance. In its RCRA permit application to the state of New Mexico, the DOE has applied for this groundwater monitoring waiver. However, the NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a groundwater monitoring waiver. Because of this, the DOE has prepared a postclosure groundwater monitoring plan for implementation after the completion of final facility closure.

An EPA RCRA document, *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*, (EPA 1986) provides guidance for developing RCRA permit applications. This guidance document describes hydrological well monitoring at hazardous waste management facilities. In Section 10.3 of the EPA document, two postclosure monitoring items are discussed. The EPA states, "Postclosure care must provide for a period of at least 30 years after completion of the authorized closure of the repository. If ground-water monitoring systems are utilized during the repository active life, they must also be operated and maintained throughout the postclosure care period" (EPA 1986). As stated, monitoring groundwater is not always required but when monitoring is required and performed during the operational period, the wells must be monitored for 30 years after closure.

The DOE has installed six groundwater monitoring wells in the Culebra. Three wells are located upgradient of the WIPP to provide background information against which to compare downgradient well data. The other three wells are located downgradient. One other well has been installed to sample groundwater in the Dewey Lake. The RCRA specifications are used as guidelines in installing the wells to the extent practicable.

There are no unique requirements applicable to the WIPP contained within 40 CFR Parts 265 or 270 that are outside the monitoring described in this postclosure monitoring program.

### *MON.3.4 40 CFR § 268.6*

In 40 CFR § 268.6(a)(4), the EPA states, "A monitoring plan that detects migration at the earliest practicable time..." is required when a no-migration variance is requested.

The WIPP has petitioned for a no-migration variance which, as stated in this regulation, requires a postclosure monitoring plan. The DOE intends to operate a single postclosure monitoring plan which satisfies the requirements of both 40 CFR § 268.6 and 40 CFR Part 191.

### *MON.3.5 Agreement for Consultation and Cooperation*

The Agreement for Consultation and Cooperation is an agreement between the state of New Mexico and the DOE (DOE 1981). This agreement defines specific legal areas of responsibility for the two parties. In the agreement, two specific areas relating to postclosure monitoring are addressed. They are

> The level of environmental radiological surveillance developed during the operational phase shall be continued during and for at least two years following complete decommissioning and decontamination of the surface facilities. This is to include both the State and the Department of Energy's programs. In addition, increased surface soil and vegetation samples will be collected and analyzed to ensure decontamination standards in effect at the time are met. (DOE 1981)
>
> The final environmental radiological surveillance phase will primarily serve to ensure the public that the re-suspension of contaminated ground surface particles, if any, is not creating a potential long-term inhalation problem. The minimum program projected at this time and to be continued for a period of not less than five (5) years following the termination of the decommissioning and decontamination phase is:
>
> (A) Intermittent operation of the state-operated high volume air sampling stations.
> (B) Four annual soil surface samples.
> (C) Four annual water samples.
> (D) Thermoluminescent dosimeters. (DOE 1981)

The radiological part of the environmental monitoring plan (Appendix EMP) for the WIPP facility fulfills the first requirement (DOE 1994a, Section 5.3, Radiological Environmental Monitoring). The total number of samples taken can be increased as necessary. The appropriate section of the environmental monitoring plan can also be used for items (A), (B), and (C). A determination was made by the DOE to discontinue the environmental thermoluminescent dosimeters efforts at and around the WIPP. The Environmental Evaluation Group concurred with the DOE determination. The DOE and Environmental Evaluation Group determined that environmental thermoluminescent dosimeters would not detect releases at the site because they are designed primarily to detect penetrating radiation. The waste to be emplaced at the WIPP contains predominantly alpha emitters (nonpenetrating). Therefore, no environmental thermoluminescent dosimeters monitoring will be performed by DOE after closure (DOE 1994a, WD 1990).

## MON.4 Preclosure Monitoring

Attachment MONPAR to this appendix documents the results of the analysis conducted to determine the effects of disposal system parameters on the containment of waste in the disposal system as required by 40 CFR § 194.42(a). The analysis also documents decisions not to monitor particular parameters. This information is required by 40 CFR § 194.42(b).

Information from the monitored parameters may be used to verify the reliability of models used in the performance assessment analysis. Where applicable, modifications to the models will be made to update the performance assessment during the five-year recertification periods. Table MON-1 describes all the preclosure parameters to be monitored.

### Table MON-1. Preclosure Monitorable Parameters

| Parameters | Comments |
|---|---|
| **SALADO PHYSICAL PARAMETERS** | |
| Creep closure | Direct measurement in open areas of repository |
| Extent of deformation | Direct measurement in open areas of repository |
| Initiation of brittle deformation | Analysis of monitored data |
| Displacement of deformation features | Direct observation and measurement in open areas of the repository |
| **NON-SALADO HYDROLOGICAL PROPERTIES** | |
| Culebra brine composition | Analysis of brine samples collected from water quality sampling program (WQSP) wells |
| Culebra well water level | Direct measurements from WIPP wells |
| Culebra groundwater flow direction | Analysis of well water levels |
| Castile brine reservoir location | Observed based upon drilling activity in the Delaware Basin |
| Drilling practices | Observed based upon drilling activity in the Delaware Basin |
| **WASTE RELATED PARAMETERS** | |
| Waste activity | Waste characterization information |
| **SUBSIDENCE** | |
| Subsidence | Direct measurements at benchmark locations |

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### *MON.4.1 Geomechanical Parameters*

The ground-control program at the WIPP facility involves a conservative approach to ensure that the underground repository is safe from any unplanned roof or rib falls. From the moment an excavation is mined and throughout the life of the opening, care is taken to remove or restrain any loose, unsafe pieces of ground. As the openings age, areas of the roof, ribs, and floor may become unstable. To prevent this from occurring, a comprehensive ground control monitoring and support system has been implemented.

The continuation of the ground-control program and use of the associated instrumentation during the preclosure phase of WIPP operations will provide information about the physical response of the Salado to the excavations. Specifically, the following parameters will be monitored

- creep closure,
- extent of deformation,
- initiation of brittle deformation, and
- displacement of deformation features.

These parameters are only available for monitoring during the preclosure period.

MON.4.1.1 Ground Control Description

There are two major categories for the ground-control support systems, the rock-bolt systems and the supplementary systems. The rock-bolt systems comprise both mechanically anchored bolts and resin-anchored threaded bars. The supplementary systems include cable with mesh, truss, and/or other components.

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

- ground stability is maintained as long as access is possible,
- ground-control maintenance efforts will necessarily increase with the age of the openings,
- ground-control plans are specific, yet flexible, and
- regular ground-control maintenance is necessary.

The approach used in the ground-control program at the WIPP facility uses experience gained from observation and analysis of salt behavior in the underground repository. This experience allows various projections to be made regarding future ground-support requirements.

One of the key elements incorporated into this approach is that salt moves, or creeps. Because of its plastic nature, salt tends to flow into any available opening. Ground-support systems cannot resist salt creep, so to provide long-term support, the ground-control system must be able to accommodate the continuous creep of salt and restrain broken or fractured rock in the roof areas.

As more information becomes available regarding the long-term behavior of the WIPP underground excavations, the ground-control maintenance plan will be revised accordingly.

The long-term plans are, therefore, designed to be flexible enough to accommodate any necessary future changes. The ground-control plan is, and will continue to be regularly reviewed and revised as iterative, periodic evaluations are performed and the need is identified.

Prior to waste emplacement in any specific area (room), the plans (for Panels 2 through 8) are to spot bolt with short, mechanically anchored bolts as needed. If spalls or loose ground are encountered, mesh or an equivalent restraint will be used in conjunction with these bolts to secure any loose ground encountered during normal inspection processes. These bolts will not penetrate through to the next clay and anhydrite interface and will be anchored within the beam formed by the mine roof and the clay and anhydrite interface above. This is the primary or initial support that will be used in Panels 2 through 8.

As deteriorating ground conditions require, pattern bolting will be used. However, based on experience with the Site and Preliminary Design Validation (SPDV) rooms and the rooms in Panel 1, pattern bolting will likely not be needed until two to five years after excavation. The expert panel that was convened to study Panel 1 in 1991 (DOE 1991) concluded that the then-current support technology of 10-foot- (3-meter-) long mechanical bolts used in Panel 1 was adequate to ensure stability for 7 to 11 years from the time of excavation. These bolts were installed beginning approximately two years after initial excavation on a pattern described as a 5-foot by 5-foot (1.5-meter by 1.5-meter) offset pattern (one bolt per 25 square feet [2.3 square meters]). Experience in Panel 1 confirms the conclusion of the expert panel. Plans call for bolt systems installed in future bolt patterns to be equal to or in excess of the bearing characteristics of the mechanically anchored bolts used in the primary pattern in Panel 1.

Rigid support systems are currently available that provide superior load bearing capacity and ductility when compared to mechanically anchored bolts. These include threaded bars, for example, DSI or Williams manufacture, and cable bolts, for example, Rocky Mountain Bolt or Jenmar manufacture. In addition, several yielding systems are now available that also provide superior load bearing capacities and have yielding capabilities in ranges exceeding one foot. These include yielding cable bolts, for example, Rocky Mountain Bolt or Western Support Systems manufacture, and slip nut systems, for example, DSI manufacture. 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. In all cases, bolts will be located no more than 5 feet (1.5 meters) apart (one bolt per 25 square feet [2.3 square meters]) in the center half of a room (8.25 feet [2.5 meters] each side of centerline) where the potential for a detaching wedge exists. The pattern support in the center half of the room will be anchored above the first clay and anhydrite interface. Pattern support near the ribs will be capable of supporting spalls or fractured ground typically found near ribs, but is not expected to penetrate the first clay and anhydrite interface. Mesh will be used as appropriate to control small pieces of broken rock.

The justification for selection of these systems includes their demonstrated ability to support the expected loads. In the case of yielding systems, they will be selected based on their support capabilities and the ability to accommodate expected rock deformation.

MON.4.1.2 Geomechanical Monitoring

The geomechanical monitoring program at the WIPP facility is an integral part of the ground-control program (see Figure MON-1). Waste disposal rooms, drifts, and geomechanical test rooms will be monitored to provide confirmation of structural integrity. Geomechanical data on the performance of the repository shafts and excavated areas are collected as part of the geotechnical field-monitoring program. The results of the geotechnical investigations are reported annually. The report describes monitoring programs and geomechanical data collected during the previous year.

The ground control monitoring system is a commercially available, computerized process-control and real-time data acquisition system. This system is used in industry to control such things as drive belts, fans, pumps, and alarms. The primary use of the system at the WIPP is for geotechnical data acquisition.

At the WIPP, the system is presently used to monitor rockbolt loadcells, extensometers, convergence meters, strain gauges, and joint meters at various locations in the repository.

The geomechanical monitoring system provides in situ data to support the continuous assessment of the design for underground facilities. Specifically, the geomechanical monitoring system provides for

- early detection of conditions that could affect operational safety,
- evaluation of disposal room closure that ensures safe access,
- guidance for system and component design modifications, and
- data for interpreting the behavior of underground openings using established design criteria as a benchmark.

The instrumentation components and systems in Table MON-2 are candidates for use in support of the geomechanical program. In addition to the over 100 installed extensometers, the geomechanical monitoring system includes over 400 convergence locations throughout the repository and shafts. These locations are comprised of anchor points installed in walls permitting repeatable measurements to be taken manually with a tape extensometer. The tape extensometer is capable of accuracy of 0.007 inches through the use of a dial indicator. The frequency of readings by location varies with an overall policy to read each location once per calendar quarter. Actual frequency of individual location monitoring is determined by the cognizant engineer based upon operational requirements and long-term excavation

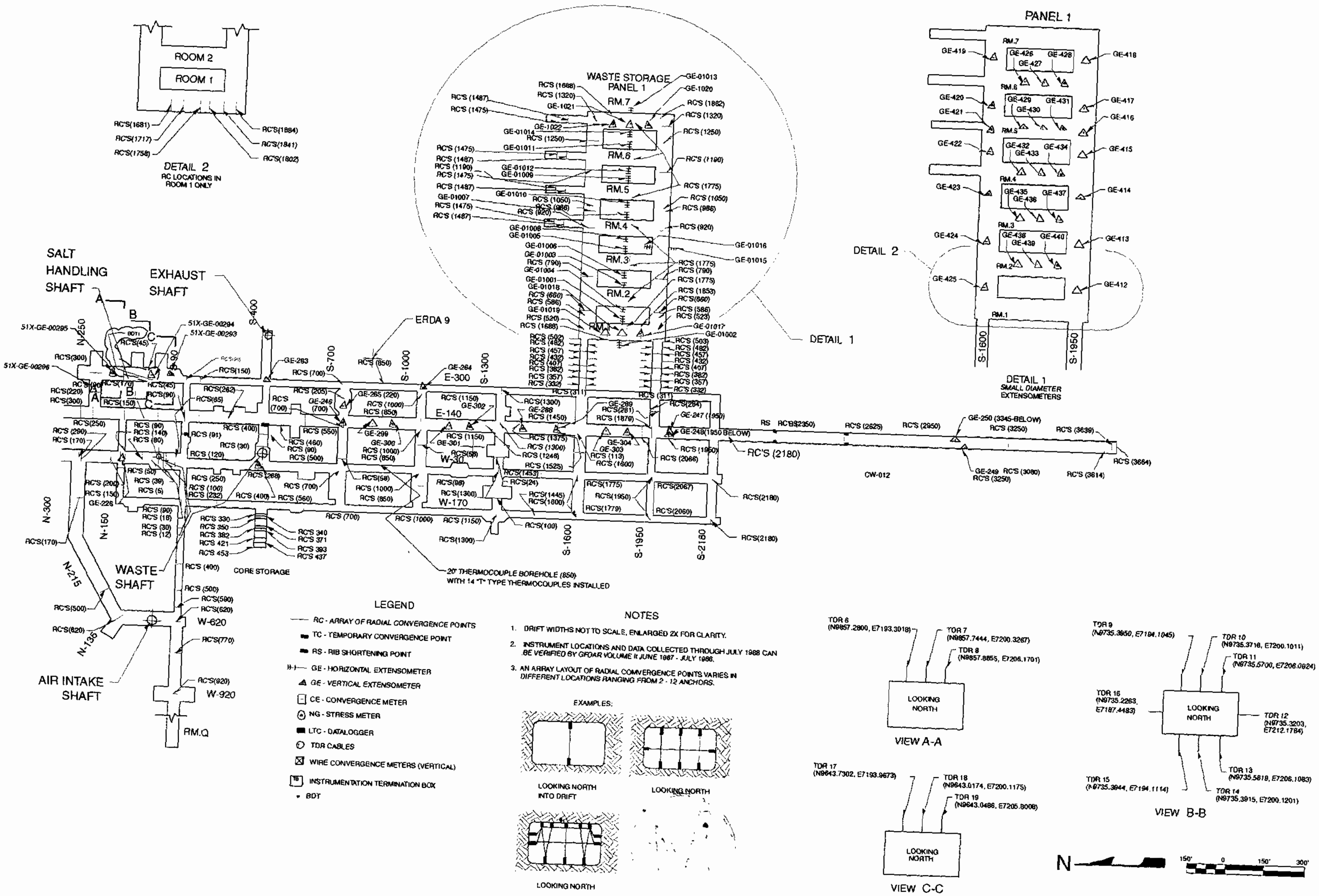


**Figure MON-1. Layout and Instrumentation of Geomechanical Monitoring System - as of 1/96**

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## Table MON-2. Instrumentation Used in Support of the Geomechanical Monitoring System

| Instrument Type | Features | Parameter Measured | Range |
|---|---|---|---|
| Borehole Extensometer | The extensometer provides for monitoring the deformation parallel to the borehole axis. Units suitable for up to five measurement anchors in addition to the reference head. Maximum borehole depths shall be 50 feet (15 meters). | Cumulative deformation | 0 to 2 inches (0 to 0.05 meters) |
| Borehole Television Camera | Closed circuit television may be used for monitoring areas otherwise inaccessible, such as boreholes or shafts. | Video image | N/A |
| Convergence Points and Tape Extensometers | Mechanically anchored eyebolts to which a portable tape extensometer is attached. | Cumulative deformation | 2 to 50 feet (0.6 to 15 meters) |
| Convergence Meters | Includes wire and sonic meters. Mounted on rigid plates anchored to the rock surface. | Cumulative deformation | 2 to 50 feet (0.6 to 15 meters) |
| Inclinometers | Both vertical and horizontal inclinometers are used. Traversing type of system in which a probe is moved periodically through casing located in the borehole whose inclination is being measured. | Cumulative deformation | 0 to 30 degrees |
| Rock Bolt Load Cells | Spool type units suitable for use with rock bolts. Tensile stress is inferred from stain gauges mounted on the surface of the spool. | Load | 0 to 300 kips |
| Earth Pressure Cells | Installed between concrete keys and rock. Preferred type is a hydraulic plate connected to a vibrating wire transmitter. | Lithostatic pressure | 0 to 1000 pounds per square inch |
| Piezometer Pressure Transducers | Located in shafts and of robust design and construction. Periodic checks on operability required. | Fluid pressure | 0 to 500 pounds per square inch |
| Strain Gauges | Installed within the concrete shaft key. Suitably sealed for the environment. Two types used—surface mounted and embedded. | Cumulative deformation | 0 to 3,000 microinches per inch (embedded)<br>0 to 2,500 microinches per inch (surface) |

performance. Weekly schedules control the program. In addition, background observation are made in all accessible areas at least annually. Hardcopy and electronic records meeting QA documentation requirements in Appendix GTMP provide the historical records of measurements and observations.

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

Remote polling of the geomechanical instrumentation will be performed at least once every month. The results from the remotely read instrumentation will be evaluated after each scheduled polling. Documentation of the results will be provided annually in the geotechnical analysis report. This frequency will be increased as necessary.

Data from remotely read instrumentation are maintained as part of a geotechnical instrumentation system. The instrumentation system provides for data maintenance, retrieval, and presentation. The instrumentation system's cognizant engineer first retrieves the data from the instrumentation system and verifies their accuracy by assuring the measurements were taken in accordance with applicable instructions and that equipment calibration is known. Next, the cognizant engineer reviews the data after each polling to assess the performance of the instrument and of the excavation. Data that appear anomalous are detected during this polling and are investigated to determine the cause (instrumentation problem, error in recording, changing rock conditions). The data are then processed to calculate various parameters such as the change between successive readings and deformation rates. Unexpected deformation rates are investigated by geotechnical engineering to determine if remedial action is needed.

The stability of an open panel excavation is generally determined by the rock deformation rate. The excavation may be considered unstable when there is a continuous increase in the deformation rate that cannot be controlled. Evaluations will be conducted to assess the effectiveness of the roof support system and estimate the stand-up time of the excavation.

MON.4.1.3 Monitoring Experience

The DOE established a geotechnical baseline during the SPDV phase as documented in Appendix DVR. Ongoing measurements are reported annually. Much experience in the use of geomechanical instrumentation was gained as the result of performance monitoring of Panel 1, which began at the time of completion of the panel excavation in 1988. The monitoring system installed at that time involved simple measurements and observations, for example, vertical and horizontal convergence rates, and visual inspections. Minimal maintenance of instrumentation is required, and the instrumentation is easily replaced if it malfunctions. Conditions throughout Panel 1 are well known. The monitoring program continues to provide data to compare the performance of Panel 1 with that established elsewhere in the underground facility. Panel 1 performance is characterized by the following:

- The development of bed separations and lateral shifts at the interfaces of the salt and the clays underlying the anhydrites a and b,
- Room closures. A closure caused only by the roof movement will be separated from the total closure,
- The behavior of the pillars,
- Fracture development in the roof and floor, and
- Distribution of load on the support system.

Roof conditions are assessed from observation boreholes and extensometer measurements. Measurements of room closure, rock displacements, and observations of fracture development in the immediate roof beam are made and used to evaluate the performance of a panel. A description of the Panel 1 monitoring program was presented to the members of the geotechnical experts panel (DOE 1991) who concurred that it was adequate to determine deterioration within the rooms and that it could provide early warning of deteriorating conditions.

The assessment and evaluation of the condition of WIPP excavations is an interactive, continuous process using the data from the monitoring programs. Criteria for corrective action are continually reevaluated based on performance to date. Actions taken are based on these analyses and planned utilization of the excavation. Because WIPP excavations are in a natural geologic medium, there is inherent variability from point to point. The principle adopted is to anticipate potential ground-control requirements and implement them in a timely manner rather than to wait until a need arises.

### *MON.4.2 Hydrological Parameters*

The WIPP's groundwater monitoring plan is described in detail in Appendix GWMP. The continuation of this program throughout the preclosure phase will provide information about the following specific parameters:

- Culebra groundwater composition,
- Change in Culebra groundwater flow direction, and
- Culebra well water level.

MON.4.2.1 Groundwater Monitoring Description

Appendix GWMP describes the basis for the groundwater monitoring plan, the organization of the program, the QA for the groundwater monitoring plan, and the sampling program description. Water quality sampling locations are shown in Figure MON-2 (WQSP-1 through WQSP-6A) for Culebra water samples. The locations of previous water quality sampling wells are shown in Figure MON-3. Sampling frequency is defined in Table MON-3 to be annually. However, the DOE is currently collecting background samples on these wells. This will involve a minimum of four semiannual samples prior to the end of fiscal year 1997. Analytes of interest are listed in Table MON-4. Background samples will be analyzed for target analytes to allow precise analyses of samples collected from locations within the monitoring area. Analytical methodologies used will be EPA-recommended procedures as described in EPA Report SW-846 *Test Methods for Evaluating Solid Waste,* third edition, November 1986 (EPA 1988a). The prescribed practical quantitation limits are the lowest concentrations of analytes in groundwaters that can be reliably determined within specified

**Table MON-3. Typical Sampling Schedule**

| Type of Sample | Sampling Locations[a] | Sampling Frequency |
|---|---|---|
| Liquid influent | 1 | Annually |
| Liquid effluent | 1 | Annually |
| Airborne effluent | 3 | Continuously |
| Meteorology | 2 | Continuously |
| Atmospheric particulate | 7 | Weekly |
| Vegetation radioanalysis | 7[b] | Annually |
| Beef radioanalysis | 2 | Annually[b] |
| Game bird radioanalysis | 1 | Annually |
| Rabbit radioanalysis | 2 | Annually |
| Deer radioanalysis | 2 | Annually |
| Fish radioanalysis | 2 | Annually |
| Soil radioanalysis | 6 | Annually |
| Surface-water radioanalysis | 12 | Annually |
| Groundwater | 7 | Annually[c] |
| Groundwater levels | 69 | Monthly |
| Sediments radioanalysis | 10 | Annually |
| Aerial photography | 1 | Annually |
| Soil chemistry | 7 | Annually |
| Wildlife survey | 4 | Annually |

[a] Sampling locations are shown in the Site Environmental Report (Appendix SER).
[b] If available.
[c] Semiannual sampling will be conducted on wells WQSP 1 through 6 and 6a until three samples are collected for establishing baseline conditions. Annual samples will be taken subsequently.

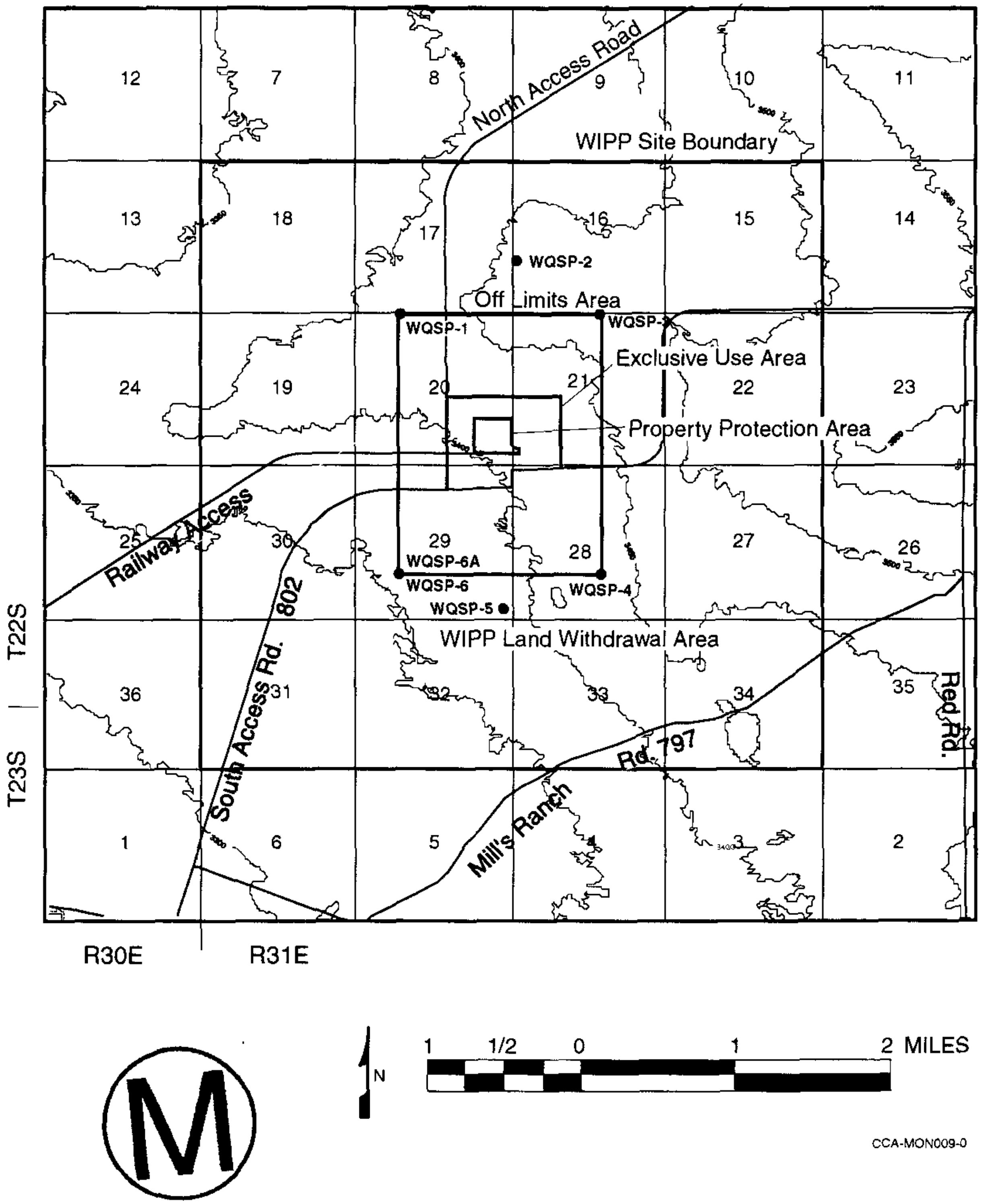


Figure MON-2. Location of the New Water Quality Sampling Wells

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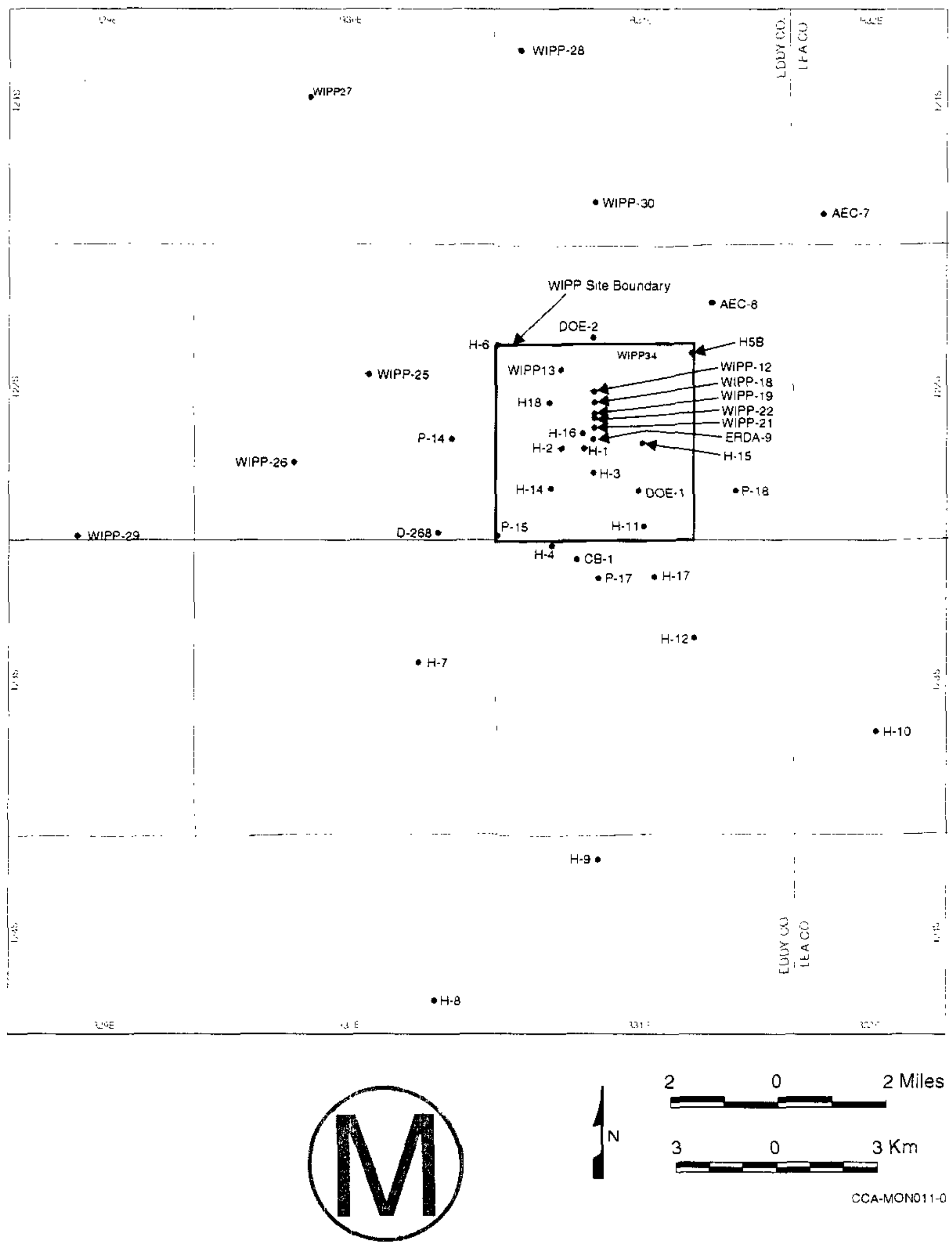


**Figure MON-3. Groundwater Level Surveillance Wells**

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## Table MON-4. Typical Environmental Surveillance Analyses

| Type of Sample | Analysis |
|---|---|
| Liquid influent | Radionuclides |
| Liquid effluent | Specific radionuclides, chemical constituents |
| Airborne effluent | Gross, $\beta$, specific radionuclides |
| Meteorology | Temperature, wind speed, wind direction, precipitation, dewpoint, barometric pressure |
| Air quality | Total suspended particulates |
| Vegetation radioanalysis | Specific radionuclides |
| Beef radioanalysis | Specific radionuclides |
| Game bird radioanalysis | Specific radionuclides |
| Rabbit radioanalysis | Specific radionuclides |
| Deer radioanalysis | Specific radionuclides |
| Fish radioanalysis | Specific radionuclides |
| Soil radioanalysis | Specific radionuclides |
| Surface-water radioanalysis | Specific radionuclides |
| Groundwater | Specific radionuclides, chemical constituents[a] |
| Sediments radioanalysis | Specific radionuclides |
| Aerial photography | Area of land disturbed |
| Wildlife survey | Bird and small mammal population densities |
| Salt impact study: Soil chemistry | pH, electrical conductivity, sodium, chloride, magnesium, calcium, potassium |

Specific radionuclides = $^{238}$Pu, $^{239}$Pu, $^{240}$Pu, $^{242}$Pu, $^{233}$U, $^{241}$Am, $^{244}$Cm, $^{232}$Th, $^{237}$Np, $^{226}$Ra, $^{137}$Cs, $^{90}$Sr, $^{60}$Co, $U_{nat}$, and $Th_{nat}$.

Chemical constituents = chloride; iron; manganese; phenols; sodium; sulfate; pH; specific conductance; total organic carbon; total organic halogen; Specified RCRA constituents; antimony; arsenic; barium; beryllium; cadmium; chromium; fluoride; lead; mercury; nickel; nitrate; selenium; silver; thallium; zinc; endrin; methoxychlor; toxaphene; 2-4-D; 2,4,5-TP silvex; radium; turbidity; coliform bacteria. Additional analytes may be specified in the WIPP facility hazardous waste permit.

[a] For the purposes of establishing baseline values in wells WQSP 1-6 and 6a, the analyses will include all 40 CFR Part 264 Appendix IX constituents.

limits of precision and accuracy by the prescribed methods under routine laboratory operating conditions. Data analysis will be conducted in such a way that it will provide an objective and reliable means for interpreting data while relating it to the objectives of the data collection program. For the groundwater monitoring plan the principal goal of data analyses is the comparison of a data point or data set to equivalent data collected at another location and at an earlier time (such as preoperational baseline data or data collected at a control location), or to a fixed standard.

The Culebra groundwater composition and flow were characterized and documented in the *Background Water Quality Characterization Report for the Waste Isolation Pilot Plant,* DOE-WIPP 92-013 (DOE 1992).

Individual grab samples are taken from each well by pumping the well. However, prior to taking the final sample, serial sampling is conducted to ensure that a representative final sample is obtained. Typically, a well is pumped for many hours prior to beginning serial sampling. The pumping rate varies from less than 1 gallon per minute to more than 10 gallons per minute depending upon the characteristics of the particular well being sampled. The final sample is taken through a dedicated nylon line to ensure no contamination from a metal line will occur.

Since many of the chemical constituents that are measured are not chemically stable and need to be preserved, samples are treated where required with either high purity hydrochloric acid, nitric acid, or sulfuric acid. This treatment information is recorded on the final sample checklist for use by field personnel when collecting samples. A uniquely numbered Chain of Custody form and Request for Analysis form are used to track the samples. The primary consideration for storage or transportation is that samples must be analyzed within the prescribed holding times. Insulated shipping containers packaged with reusable blue ice are used to keep the samples cool during transport to the contract laboratory. Procedures for sample tracking and preservation are generated, approved, and maintained in accordance with an approved Quality Assurance Plan.

Results of the Groundwater Monitoring Program are published annually in the *Site Environmental Report* (DOE 1994b).

MON.4.2.2 Groundwater Analysis

Several levels of analyses are required for each parameter before statistically valid interpretation of data can be achieved. The type of analysis used at each level varies among parameters because of the particular characteristics of parameters and the specific objectives of monitoring. Five general levels of data analyses are described here. Analyses at each of these levels is considered for each parameter. The levels are

(1) Determination of accuracy for each point measurement by quantification and control of precision and bias,

(2) Evaluation of the effects of auto-correlation on the expected value of the point measurement as a result of location and time of sampling,

(3) Identification of the appropriate model of variability, that is, a probability density distribution, for each point measurement and the calculation of descriptive statistics based on the chosen model,

(4) Treatment of data anomalies, and

(5) Interpretation of data through statistically valid comparisons (tests) and trend analysis.

Each of these levels of data analyses are described below. These descriptions also include a discussion of applicable requirements for the groundwater monitoring plan.

*MON.4.2.2.1* <u>*Accuracy*</u>

Accuracy is a measure of the closeness of a measurement to its actual, or true, value. Because the true value cannot be determined independently, accuracy cannot be absolutely determined. However, accuracy is controlled by two basic elements: bias (consistent over- or underestimation of the true value) and precision, (concentration of repeated measurements around a central [expected] value). Accuracy is maximized when bias is minimized and precision is maximized.

To some extent, precision and bias are controlled by strict adherence to sample collection, handling, and measurement protocols. Groundwater monitoring plan procedures specify the protocols for those functions performed at the WIPP and quality control procedures establish control on precision and bias for analytical work.

*MON.4.2.2.2* <u>*Temporal and Spatial Analysis*</u>

Environmental parameters vary with space and time. The effect of one or both of these two factors on the expected value of a point measurement is statistically evaluated through spatial analysis and time series analysis; however, these methods often require extensive sampling efforts that are in excess of the practical requirements of the WIPP groundwater monitoring plan. Applying these methods to a particular parameter is, therefore, limited by consideration of its relative significance in the final interpretation of the data.

In particular, spatial analysis has limited use in this program, although the effect of spatial auto-correlation on the interpretation of the data is considered for each parameter. Spatial variability is accounted for by selecting the optimal sampling locations. Data analysis is performed on a location-specific basis, or data from different locations are combined only when the data have been determined to be statistically homogeneous.

Time series analysis plays a more important role in data analysis for the groundwater monitoring plan. Parameters are reported as time series, either in tabular form or as time plots. For key time series parameters, these plots are in the form of control charts on which control levels will be identified based on preoperational data base, fixed standards, control location data bases, or other standards for comparison. Where significant seasonal changes in the expected value of the parameter are identified in the preoperational database or in the control locations, corrections in the control levels that reflect the seasonal change are made.

*MON.4.2.2.3* *Distributions and Descriptive Statistics*

For data sets that include more than 10 data points that are homogeneous in space and time (including seasonal homogeneity), and have less than 10 percent missing data, a test for conformance to the normal distribution is performed. A probability plot is an accepted method for performing this test; however, more powerful tests of normality, such as the W Test, or D'Agostino's Test are more accurate. Any standard best-fit test is acceptable, provided the assumptions of the tests are met.

If normality is not observed, the data will be log-transformed and retested for normality. If the transformed data fit a normal distribution, the original data will be accepted as having log-normal distribution. If normality is still not observed, two courses of action may be taken. One option is to continue to test the fit to standard families of distributions, such as the gamma, beta, and Weibull, with proper modifications to subsequent analyses based on these results. The other possible course of action is to use nonparametric methods of data analysis.

For data sets smaller than 10, but homogeneous and complete, the log-normal distribution is assumed. Data sets with more than 10 percent missing data are analyzed using nonparametric methods. Nonhomogeneous data sets are divided into homogeneous subsets and each of these analyzed individually.

Descriptive statistics are calculated for each homogeneous data set. At a minimum, these calculations include determining a central value and a range of variation. The central value is the arithmetic mean of the untransformed data if the data are not censored at either end. If the data are censored, either a trimmed mean or the median is used as the central value (which may be within the censored range). If the data set is greater than 10 and is uncensored, the standard deviation is calculated and used as a basis for the reported range in variation. If these criteria are not met, the range between the 25th and 75th percentiles is used.

*MON.4.2.2.4* *Data Anomalies*

Data anomalies include data points reported as being below the limit of detection or otherwise censored over a specific range of values, missing data points occurring randomly in the data set, and outliers that cannot be ascribed to a known variation source.

Whenever possible, values that are below detection limits are obtained and incorporated into the database for statistical analysis. When values are not available, alternative methods of analysis, as described in previous sections, are used. In particular, the use of nonparametric statistics is required.

Missing data points comprising less than 10 percent of the data set do not affect data analyses. Results based on data where more than 10 percent are missing are identified as such at the time of reporting. Consideration of the potential effect of missing data must be made when the majority of the data are missing from a discrete time span.

An outlier is defined as any data point occurring in either extreme upper or lower range of the data distribution for which there is less than 0.01 probability of occurrence. For normally distributed data, this is roughly 2.3 or more standard deviations above or below the mean. When no probability model is identified, outliers may only be found through visual inspection of the data.

If an outside source of variation is not identified to account for outliers in a data set, the outlier(s) is included in the data set and is considered in all subsequent analyses. If the inclusion of such outliers is found to affect the final results of the analyses significantly, results both with and without outliers are reported.

##### *MON.4.2.2.5* *Comparisons and Reporting*

Comparisons between data sets are performed using standard statistical tests. The selection of the specific test is dependent upon the relative power of the test and the degree to which the underlying requirements of the test are met. In addition to tests comparing data from distinct locations and times, trend analyses are performed on time series where sufficient data exist. A 95-percent confidence level will be used for the final interpretation of results.

Citation of the source of the test method or the software used to perform the tests will be made when results are reported. Data and subsequent calculated values are reported in the annual site environmental report in accordance with standard rules for significant figures.

### *MON.4.3 Gaseous Parameters*

VOC monitoring has been performed at the WIPP facility to establish background VOC levels at the site. During initial stages of the disposal phase, confirmatory VOC monitoring will be performed in the repository. Appendix VCMP describes the confirmatory VOC monitoring program in detail.

#### MON.4.3.1 Background Volatile Organic Compound Monitoring

The VOC monitoring program has focused on the air pathway since 1991. The airborne emission of VOCs is the only credible pathway for release from the WIPP during disposal operations, and this pathway will be eliminated upon final facility closure. With more than four years of data collected, a credible basis for determining the WIPP facility's background levels of the targeted VOCs has been established.

The VOC monitoring plan conducted for the WIPP to date is described in detail in the *VOC Monitoring Plan* (WEC 1994a). The program monitored the air exhausted from the mine's ventilation shaft for VOCs that might have been released from the test wastes. To differentiate between ambient or background VOCs from aboveground and underground sources and VOCs released from transuranic (TRU) -mixed wastes, VOC concentrations have been measured at the following locations:

- near the top of the exhaust shaft (Station VOC-1),
- near the air intake shaft (Station VOC-2), and
- ventilation air intake passageways to the waste-containing rooms (Station VOC-8).

Sampling followed a regular schedule with the samples analyzed for the quantities of five target VOCs. The samples were then analyzed for other organics present in sufficient quantities to be detected. The five target compounds were carbon tetrachloride, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane. These compounds were selected because of their prevalence in TRU-mixed wastes and their inclusion in the conditional no-migration determination. The *VOC Monitoring Quality Assurance Project Plan* identifies the following data quality objectives as applicable to the VOCs monitoring program (WEC 1994b)

- Method detection limit of 0.5 parts per billion or one-fifth of any health-based limit for a targeted constituent, whichever is greater,
- Precision, that is, relative percent difference between field duplicate samples, of ±15 percent,
- Accuracy of ±10 percent, and
- Data completeness of 90 percent, as adjusted statistically to account for the results of data validation audits.

The EPA Compendium Method TO-14 (EPA 1988b), which specifies passivated stainless steel canisters for sample collection, was used as guidance to meet these objectives. The analytical methods consisted of cryogenic trapping and gas chromatography and mass spectrometry. Results of the VOC monitoring program have been provided annually to the EPA. QA and quality control activities conducted in accordance with the *VOC Monitoring Quality Assurance Project Plan* (WEC 1994b) included duplicate sampling, spiked samples, and annual audits of the laboratory conducting the analyses.

MON.4.3.2 Confirmatory Volatile Organic Compound Monitoring

The concentrations of VOCs at the point of compliance during disposal operations and facility closure have been estimated to be one-third to five orders of magnitude below health-based limits. Since these calculations were based on conservative assumptions, and since the DOE has collected more than four years of data to support the validity of background levels of VOCs in air, the DOE will implement confirmatory VOC monitoring activities during the disposal phase.

The DOE has prepared a VOC monitoring plan that describes the aspects of a VOC monitoring strategy. The plan has been prepared so that the DOE can show that the assumptions and predictions used to demonstrate compliance to the environmental performance standards are valid. Validity is shown when observed emissions are equal to or less than those predicted. The VOC confirmatory monitoring plan is provided in Appendix VCMP. The confirmatory monitoring plan includes monitoring design, sampling and analysis procedures, and QA objectives. The plan was submitted in compliance with 20 NMAC 4.1, Subpart V, § 264.602, § 268.6, and § 270.23(a)(2).

The VOC confirmatory monitoring plan describes a sampling and analysis program to confirm the theoretical calculations. The monitoring program is capable of quantifying VOC concentrations in the ambient mine air at the WIPP. The confirmatory monitoring plan addresses the following information requirements:

- Rationale for the design of the monitoring program, based on possible pathways, operations, engineered and natural barriers, and monitoring locations optimized for detection, and

- Descriptions of the specific elements of the monitoring program including the type of monitoring, the location of stations, the frequency of sampling, the target analytes, the schedule for implementation, the equipment used, the sampling and analytical techniques, and the data recording and reporting procedures.

The design of the confirmatory monitoring plan was based on the results of extensive background VOC monitoring activities conducted at the WIPP. These data represent the anticipated background levels of VOCs during operations at the WIPP.

The DOE's intent is to collect air samples upstream and downstream of Panel 1 beginning just prior to waste emplacement and proceeding until at least six months following completion of panel closure. The DOE will continue monitoring until the criteria for terminating monitoring are met. These criteria are established in Appendix VCMP for each target analyte.

The current VOC monitoring program uses EPA Compendium Method TO-14 (EPA 1988b). The DOE has had success with TO-14 at the WIPP when care is taken in placing samplers so as to avoid high dust and if stringent cleaning requirements are imposed for the sample canisters. This level of rigor is necessary because of the extremely low concentrations of analytes that are being monitored. The DOE is evaluating the use of the Fourier Transform Infra-Red technique for monitoring VOCs at WIPP. This method is being used successfully at other locations and has recently been approved by the EPA for measuring the concentration of VOCs in the headspace gases of drums of transuranic waste. If the Fourier Transform Infra-Red technique becomes viable, the monitoring plan will be revised and the revisions will be submitted to the NMED for approval prior to implementation.

The confirmatory monitoring plan will be run under a QA plan that conforms to the document entitled, *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations* (EPA 1994). QA criteria are described in Appendix VCMP. Appendix VCMP also includes a discussion of other aspects of the QA program including sample handling, calibration, analytical procedures, data reduction, validation and reporting, performance and system audits, preventive maintenance, and corrective actions.

### *MON.4.4 Other Parameters*

A number of other parameters may be evaluated from the observation of activities included within the WIPP program and/or occurring in the WIPP vicinity. In the course of characterizing WIPP waste at other DOE facilities, waste activity is determined as part of the data needed to ensure that the waste received at WIPP meets the applicable restrictions in the Waste Acceptance Criteria.

Through continuation of monitoring the drilling activities in the nine townships centered on the township within which the WIPP is located, additional data can be developed on drilling rates for comparison to the assumed values developed from the 100-year history of Delaware Basin resource recovery. The monitoring of the drilling activities for boreholes penetrating the Castile Formation will provide additional data regarding assumptions made in performance assessment with respect to location of Castile brine reservoirs. Monitoring the well plugging and abandonment operations within the nine townships will provide information regarding the types of plugs used and their rate of use. Important deviations will be recognized and considered in performance assessment activities supporting recertification.

## MON.5 Postclosure (Long-Term) Monitoring

The basis for postclosure monitoring is found in 40 CFR Part 191, 40 CFR Part 268, and 40 CFR Part 264. 40 CFR Part 194 provides the criteria for meeting the 40 CFR Part 191 requirements. In March 1996 the EPA published EPA 402-R-95-014, *Compliance Application Guidance for 40 CFR Part 194* (EPA 1996b). The compliance application guidance provides guidance in meeting the criteria specified in 40 CFR Part 194. The regulations were reviewed and the areas that apply to postclosure monitoring are discussed below. An outline of individual design requirements is also provided.

Those parameters that will be monitored upon implementation of the postclosure monitoring program are listed in Table MON-5. The parameters identified in Section MON.4 that can be monitored during the postclosure period are the following:

- Culebra groundwater, water level changes, and changes in groundwater flow direction,
- Castile brine reservoir location, and
- drilling practices (including plugging).

### Table MON-5. Postclosure Monitoring Parameters

| | |
|---|---|
| **NON-SALADO HYDROLOGICAL PARAMETERS** | |
| Culebra brine composition | Analysis of brine samples collected from WQSP wells |
| Culebra well water level | Direct measurements from WIPP wells |
| Culebra groundwater flow direction | Observation of well water level changes over time |
| Castile brine reservoir location | Observed based upon drilling activity in the Delaware Basin |
| Castile brine reservoir pressure | Observed based upon drilling activity in the Delaware Basin |
| Drilling intensity | Observed based upon drilling activity in the Delaware Basin |
| Borehole plugging | Observed based upon drilling activity in the Delaware Basin |
| **REPOSITORY PERFORMANCE PARAMETER** | |
| Subsidence | Can be measured and evaluated against predictions and baseline database |

In addition to these parameters, continued, periodic subsidence surveys will provide data for review and analysis against predictions. This will allow the DOE to identify any data anomalies that might occur. Analysis of such anomalies, if they do occur, may provide information regarding the conceptual models used to predict long-term repository performance. Anomalous conditions would be those that are statistically different than conditions predicted by the conceptual models. Such anomalous conditions would require further investigations by the DOE to determine if the condition is detrimental to disposal system performance.

Postclosure monitoring of the repository will use subsidence monitoring as the repository's primary performance indicator. In addition, radiological environmental monitoring will be performed at the same level as was used during the operational phase for the first two years after decontamination and decommissioning, and in a limited fashion, environmental monitoring will be conducted for three years thereafter.

### MON.5.1 Postclosure Monitoring Requirements

The postclosure monitoring plan will not be implemented until after final facility closure (sealing of the shafts). The repository is scheduled to open in 1998 and is projected to operate until 2023; decontamination and decommissioning will be completed within 10 years following the final receipt of TRU waste. The postclosure monitoring plan includes provisions to review the postclosure monitoring system during the operational phase. Any changes will be made only after review and approval by the appropriate regulatory authorities.

After closure, buildings and above ground facilities will be removed, and active controls will be implemented. Postclosure monitoring techniques will be designed so as to minimize associated maintenance activities and the need for support facilities. The monitoring techniques are as stand-alone as possible since power may only be available for part of the postclosure period. The postclosure monitoring systems will be located on the surface to facilitate access for maintenance and operation. Safeguards will be provided to protect the equipment from vandalism and the environment.

Monitoring techniques that obtain useful data at reasonable cost with minimal maintenance over an extended period of time are the most favorable.

In summary, institutional postclosure monitoring requirements used as assumptions to arrive at system specifications are as follows:

- The postclosure monitoring system design shall be as human independent as practicable,
- The system must endure the conditions posed by the natural environment,
- The system must be cost-effective,
- The system must not require unreasonably large support facilities,
- The system shall require minimal maintenance and power requirements, and
- All components susceptible to vandalism shall be secured from public access.

### MON.5.2 Postclosure Monitoring System Specifications

The postclosure monitoring specifications are listed below.

- Those parameters identified in Attachment 1, MONPAR, to this appendix as applicable for postclosure monitoring will be included in the postclosure monitoring program.

- The postclosure monitoring system shall be designed and implemented so as to detect substantial deviations from expected repository performance after closure.

- The monitoring technique(s) used must not jeopardize the naturally protective nature of the disposal system and must therefore be nonintrusive.

- Monitoring will continue as long as practicable, and/or until the DOE can demonstrate to EPA that there are no significant concerns to be addressed by further monitoring.

- The groundwater monitoring plan and the water quality sampling wells shall be maintained for a minimum of 30 years after closure.

- The radiological aspect of the operational environmental monitoring plan shall be continued for a minimum of two years past decontamination and decommissioning in accordance with the C&C agreement.

- Four annual soil surface samples and four annual surface water samples shall be taken for five years after decontamination and decommissioning in accordance with the C&C agreement.

- The design of the postclosure monitoring program will depend in part on the results of data obtained during the operational phase.

- Postclosure monitoring system design shall require minimal support from humans.

- The system must endure the natural environment.

- The system must be cost-effective.

- The system must not require unreasonably large support facilities.

- All components susceptible to vandalism shall be secured from public access.

### *MON.5.3 System Description*

The basic requirements listed in the Section MON.5.1 were used to define a postclosure monitoring system that would best fulfill all the applicable requirements. The system comprises four monitoring programs of varying duration: (1) groundwater surveillance; (2) radiological environmental monitoring; (3) subsidence monitoring; and (4) observation of drilling activities.

The postclosure monitoring system will also consist of any preexisting hydrological wells plus any additional wells deemed useful. The well monitoring program that was used during the operational phase will be used during the postclosure phase. The frequency of the testing will be modified after closure to include maintenance and well casing replacement as appropriate. Testing intervals will be lengthened if previous data have been relatively constant during the operational phase. The final postclosure monitoring schedule will be determined by a closure review study.

The radiological portions of the operational environmental monitoring plan in place prior to closure will be used in postclosure monitoring for a minimum of two years after closure with limited radiological monitoring for the following three years.

Subsidence monitoring will be supported by several other systems. These systems include a subsidence network, a monitoring program, a baseline database, a closure review study, and a subsidence data study. The postclosure monitoring will be implemented until the DOE decides, and the regulators concur, that no further monitoring is required. The data collection for both the baseline database and subsidence data are verified through a QA and quality control program to assure data quality. The monitoring program will be documented through a set of operating procedures that are validated and maintained under the QA and quality control program. All actions relating to repository performance indications from the subsidence monitoring program will be resolved through the DOE office overseeing the project.

A subsidence data study will be performed during the developmental and operational (waste emplacement) phases of the WIPP. This study will provide the subsidence prediction data and gather all data for the baseline database. The findings will include the predictions and bounding conditions for repository performance and will be used to define scenarios that would characterize what measured subsidence is outside of the bounds of the predicted range. These scenarios will be used in the baseline database to provide guidance that will be used in evaluating unexpected subsidence monitoring data.

The DOE will continue to observe drilling and borehole plugging practices in the Delaware Basin, thereby gathering additional information relevant to human intrusion and the parameters in Table MON-5, as these are significant to repository performance.

A closure review study will be performed during the late operational phase that assesses the condition of the facility at closure. The study will:

- Evaluate the postclosure monitoring plan, the data generated during the operational and closure phases and regulatory requirements at the closure date,

- Update the postclosure monitoring program,

- Evaluate the necessity for continued monitoring and determine the appropriate repository parameters to be monitored, and

- Revise the postclosure monitoring schedule to account for any necessary changes based on the study findings.

The groundwater surveillance program is described in detail in Appendix GWMP. The environmental monitoring program is described in Appendix EMP. The subsidence monitoring program is described in Appendix SMP. The observation of drilling practices is described in Appendix DMP.

Technology, regulations, site management, safety requirements, and public opinions will advance and change over the period of time from now until final facility closure. A review at the time of facility closure will be performed to update the postclosure monitoring techniques and schedules. Monitoring frequencies, instrumentation, locations, and dates will be revised as appropriate.

A closure review study will be initiated to evaluate the postclosure monitoring plan and update all aspects that are not current. This plan will review the data in the baseline database and all governing regulatory issues associated with postclosure monitoring of the facility. The closure review study will determine what monitoring is required, what will be monitored, what equipment and techniques will be used, and the area and lines that will be monitored. A feasibility study will evaluate technology available at that time that can be used to accomplish the monitoring objectives.

### *MON.5.4 Monitoring Schedules*

The schedule for postclosure monitoring is based on an approach using several basic monitoring groups to implement the four parts of the monitoring program; the initial geophysical survey group, the radiological environmental monitoring plan group, the subsidence monitoring group, and the abbreviated radiological environmental monitoring group. The initial geophysical survey group will be composed of a seismic survey, a resistivity survey, an environmental monitoring survey, a gravitational survey, and a radiological aerial survey. The radiological environmental monitoring plan group (a continuation of the operational environmental monitoring program) will be performed for the first two years only. The subsidence monitoring group will include a leveling survey in the first and third year and every 10 years thereafter. The last group, the abbreviated radiological environmental monitoring group, will include only three sample types (airborne particulate, soil, and water) taken on an annual basis for at least three years following cessation of the radiological environmental monitoring plan group. The schedule for the preclosure monitoring process is detailed in Figure MON-4 and the specific postclosure monitoring schedule is shown in Figure MON-5.

## MON.6 Review of Postclosure Monitoring Technologies

Each of the technologies listed below are discussed, defining the monitoring technology and describing the past, current, and future work using this technology as related to performance monitoring. Also defined are the advantages, disadvantages, and proposed uses of the technologies in postclosure monitoring of the repository.

- Subsidence
- Seismic reflection and refraction
- Gravitational
- Electromagnetic
- Resistivity
- Direct repository monitoring

### *MON.6.1 Subsidence*

Subsidence is defined as vertical movement of the land surface anywhere in the subsidence basin. Subsidence monitoring is defined as the measurement of *relative vertical movement* of the land surface. This movement can be up (uplift) or down (subsidence) and is relative to a fixed reference. This reference is assumed fixed, even though it is subjected to the same factors that cause the surface movement and is moving also. Subsidence monitoring is used to determine the measurable vertical movement of a land mass. The techniques used to monitor subsidence measure the vertical height difference between two or more markers placed on the surface a known distance away from each other and is done with a leveling survey. Usually, one reference benchmark is used as the standard and the relative movement of other stations or benchmarks are measured to detect vertical movement over time. All subsidence measurements are relative because the reference is not fixed.

The error of the survey is determined by the equipment and distances between the stations. A first order survey has an error of one part in 100,000 and a second order survey has an error of one part in 20,000. With current technology, several thousandths of an inch vertical movement can be measured to the stated accuracy.

Subsidence can be caused by a variety of factors. Mining, hydrocarbon extraction, water injection and extraction, geological tilt, and dissolutioning are major subsidence causing factors all of which may be applicable to the WIPP over the long term.

#### MON.6.1.1 Advantages of Subsidence Monitoring

Subsidence monitoring is advantageous because it is a passive monitoring technique that is relatively simple to perform and uses well established technologies. The cost of the survey is low compared to other technologies. This technique requires little system maintenance or monitoring and has no power requirement. The benchmarks are not affected by weather and

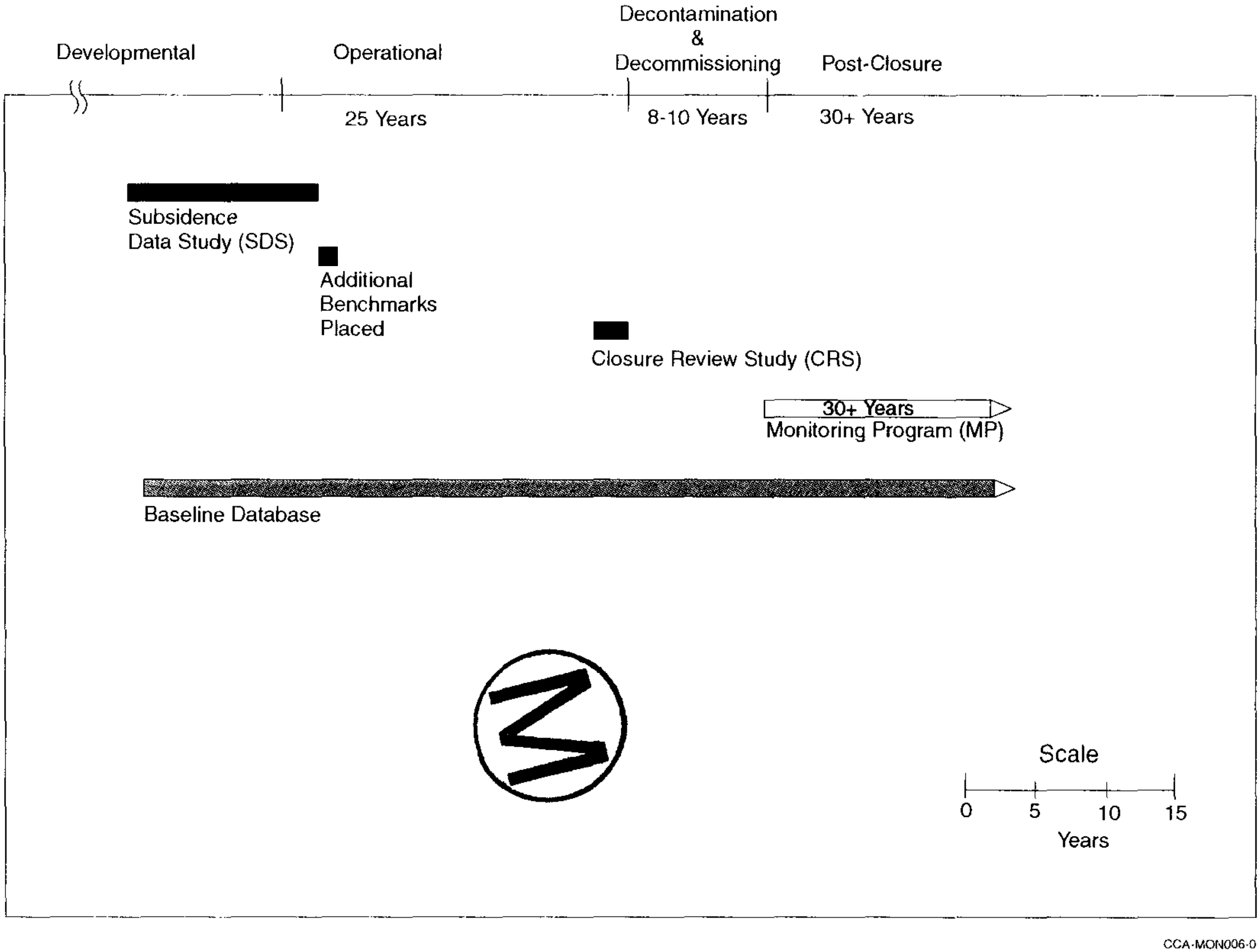


Figure MON-4. Preclosure Monitoring Program Conceptual Schedule

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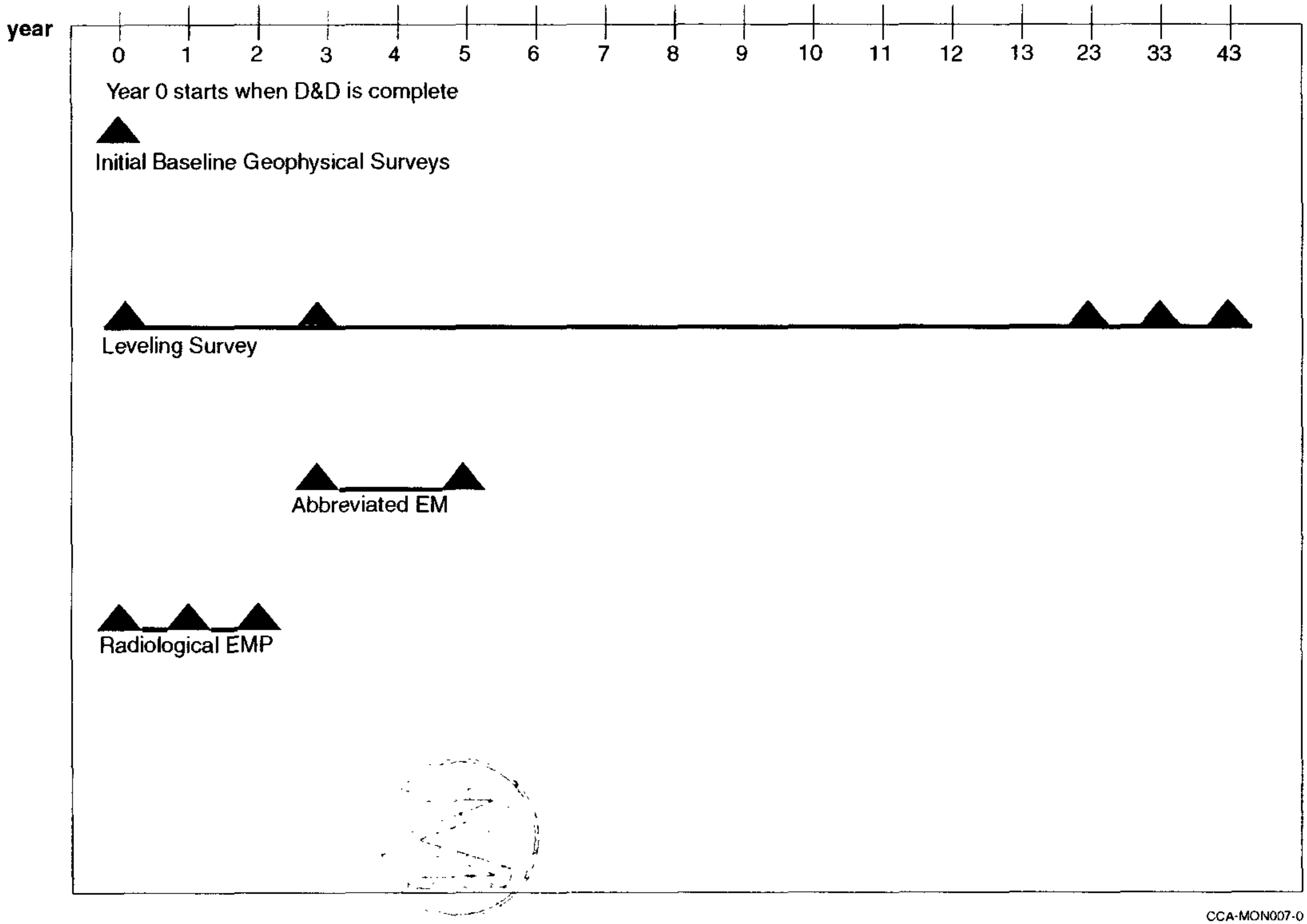


**Figure MON-5. Postmonitoring Schedule**

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can last for hundreds of years. Benchmarks can be replaced if required and the data can be offset to account for the change without affecting data quality.

MON.6.1.2 Disadvantages of Subsidence Monitoring

The disadvantages associated with subsidence monitoring is in the benchmark placement. The benchmark should be left undisturbed. Existing benchmarks may be destroyed or moved if new construction occurs over the benchmarks. The permanent markers design calls for large earthen berms around the facility after closure. The placement of the berm may cover some of the existing benchmarks and may preclude the necessary line-of-sight measurements between existing benchmarks. The benchmarks are also not currently protected, and could be destroyed during land use by ranchers, drillers, or developers. This necessitates replacing markers and incorporating new markers on the berm to maintain a line-of-sight reference with the benchmarks. Future advancements in global positioning systems may eliminate the need for line-of-sight placement of the benchmarks.

MON.6.1.3 Past Subsidence Work

During the initial site selection process, 195 miles (314 kilometers) of first order, Class 1 leveling survey was performed in 1977 by the National Geodetic Survey (NGS). Later, new survey lines were established that connected the previous first order benchmarks through Carlsbad to second order survey lines through Eunice and Hobbs. Benchmarks were placed over the Nash Draw from the north end to the Remuda Basin, over potash mines, the WIPP site, and the San Simon Sink (Powers 1993). Independent of the NGS benchmarks, an additional 52 benchmarks were installed over the WIPP site and surrounding area.

The NGS network was resurveyed in 1981 and the relative movement between Carlsbad and the WIPP site was measured to be about 0.8 inches (2 centimeters). The relationships between subsidence and potash mining in the WIPP vicinity are discussed in Powers (1993). From data in this report, potash mining was shown to have caused significant subsidence at mines close to the WIPP. Two benchmarks over the Mississippi Chemical Corporation mine measured relative to Carlsbad show 10- and 40-inch (25.4- and 102.7-centimeter) movement downward from 1977 to 1981. Powers (1993) also discusses mining effects on surface subsidence at other mines and correlated a relationship between mining and the surface area effects. This effect is of importance to WIPP monitoring in that estimations of area mining and WIPP mining can be calculated into the subsidence predictions.

From Powers (1993), "In May, 1982, the NGS placed and leveled 15 additional high-quality benchmarks along a north-south line across the position of WIPP 12 (1 mile [1.6 kilometers] north of WIPP surface facilities) and the underlying brine reservoirs in the Castile Formation." After testing and fluid production of approximately 27,058 barrels of brine from the brine reservoir, the NGS resurveyed these benchmarks in January, 1983. According to Powers (1993), "The major difference in elevation across these 15 benchmarks from May, 1982 to

January, 1983, is about 6 to 7 millimeters between the north end of the line and the approximate position of the WIPP."

### MON.6.1.4 Subsidence Predictions

Subsidence predictions as a result of mining can also be calculated empirically. Techniques such as mass conservation, National Coal Board, and profile and influence functions can be used to calculate subsidence caused by mining. The influence function technique can estimate subsidence from room and pillar type mining, which is the type of mining used at the WIPP (Sutherland and Munson 1983). Four studies have been performed that have calculated subsidence predictions, the results are found in the *Final Environmental Impact Statement (FEIS)* (DOE 1980), the *Final Safety Analysis Report (FSAR)* (DOE 1990), Sandia National Laboratories' (SNL's) 1991 comparison with 40 CFR Part 191 (WIPP Performance Assessment Division 1991), and the *Backfill Engineering Analysis Report (<u>BEAR</u>)* (WEC 1994c). The following details each report's maximum subsidence predictions:

MAXIMUM SUBSIDENCE PREDICTIONS

| | |
|---|---|
| FEIS | |
| 70-percent backfill density | 1-foot (0.3-meter) subsidence |
| 50-percent backfill density | 1.6-foot (0.5-meter) subsidence |
| No backfill | 3.28-foot (1.0-meter) subsidence |
| | |
| FSAR | |
| Shaft pillar area | 1- to 1.2-foot (0.3- to 0.38-meter) subsidence |
| (backfill type and amount not specified) | |
| | |
| SNL | |
| 35° angle | 0.3-foot (0.09-meter) subsidence |
| 25° angle | 0.4-foot (0.13-meter) subsidence |
| | |
| BEAR | |
| No backfill | 1.3- to 2-foot (0.40- to 0.60-meter) subsidence |
| Highly compacted backfill | 1- to 1.7-foot (0.30- to 0.52-meter) subsidence |

### MON.6.1.5 Current Work in Subsidence Monitoring

Current subsidence work includes annual monitoring, a proposed NGS, and a satellite positioning survey. The WIPP Subsidence Monitoring Program is performed annually allowing for a comparison of the data, development of a database, and analysis of subsidence characteristics at the WIPP site. The program includes surface subsidence monitoring involving twenty miles of leveling loops through approximately fifty monuments (S-Caps). Subsidence monitoring surveys include Global Positioning Satellite and surveys of the S-Caps. Figure SMP-1 (see Appendix SMP) identifies approximately 50 benchmarks (those designated "S" and "PT") distributed throughout the area of influence of the repository and excavated support regions. The annual survey is completed so as to achieve closures that exceed a minimum standard of Second Order Class II for vertical control surveys. State of the art digital leveling technology is employed for all subsidence surveys. From 1996 onward, the survey is being performed to yet higher standards to allow for upgrading the precision of measurements.

Maintenance and calibration of equipment used for monitoring is addressed in Section 2.4.4 of the Westinghouse Waste Isolation Division Quality Assurance Program Description, (see Appendix QAPD). For subsidence measurements, maintenance and calibration are performed by the equipment vendor in accordance with national standards. Equipment is only procured from, maintained, and calibrated by vendors on the WIPP approved Qualified Supplier's List.

Data, plots, graphics, and reports generated as a result of the subsidence surveys are reviewed by cognizant technical engineering personnel to ensure their adequacy and accuracy in accordance with DOE and DOE/WIPP Quality Assurance Review procedures.
The WIPP currently monitors the existing benchmarks as indicated in Figure SMP-1 (see Appendix SMP) on an annual basis (drawing by John West Engineering Co., 1-11-93).

MON.6.1.6 <u>Future Work on Subsidence Monitoring</u>

A NGS survey was performed in 1996 however the final report has not yet been published. The current plan is to resurvey about every 10 years. The last NGS survey was performed in 1982.

MON.6.1.7 <u>Define Use of Subsidence Surveys for Postclosure Monitoring</u>

This report assumes that substantial work will be performed during the operational phase to gather subsidence information and data. This data will be used to relate expected subsidence over time for various scenarios of repository performance. The effects of petroleum production, mining, and geological subsidence must be accounted for in these scenarios. These estimates would be compared to actual measurements.

During the operational phase, the current benchmarks and new benchmark network will be used to gather baseline data. After the operational phase, however, decommissioning of the surface facilities and erection of active and passive controls will eliminate some of this network. For this reason, during the decommissioning, damaged or lost stations should be replaced. Additional stations may be necessary to compensate for line-of-sight losses incurred as a result of the proposed passive permanent markers. It is expected that analysis may have determined subsidence estimates at specific locations; these locations should be included in the benchmark network.

After decommissioning and adjustment of the benchmark network, a Class 1 leveling survey will be performed to determine baseline data. The network will be monitored after closure and until monitoring is determined to be no longer necessary. The monitoring frequency is to be every third year for the first 15 years. During this time, the data will be compared to the previous trends and if no important anomalies are found, the monitoring frequencies will be adjusted to 10-year intervals.

### *MON.6.2 Seismic Reflection and Refraction Surveys*

Seismic reflection and refraction surveys are used to determine the depth, thickness, composition, and physical properties of geologic layers. Data from the survey can locate specific horizons such as water tables, clay layers, and bedrock. This technology can be used to map the geological structures of large areas at great depths. Survey results are often used by geologists to locate specific geologies that may contain hydrocarbon reserves.

This method uses seismic wave transmissions to determine geologic structure depth and composition. Seismic waves travel at different velocities depending on the soil and rock type. Hard and dense rock have higher wave velocities than soft and less dense rock. Seismic waves can travel through, reflect, or refract off of geological structures. Some of the wave energy will travel along the layers. This phenomena is used to determine depth and composition of the strata by measuring the return time of an induced wave generated at the surface and reflected and refracted back from the underlying strata.

This technique measures wave travel times through a sensor array called geophones placed over the area of interest. A seismic wave is generated by dropping a weight (anything from a hand sledge to truck-mounted ram), or by using high explosives. A seismograph is used to amplify and record the data. By using various seismic wave input energies, sensor array spacings and numbers, specific depths can be mapped. The map corresponds to a geological profile along the line surveyed. Figure MON-6 details the basic seismic surveying technique.

#### MON.6.2.1 <u>Advantages of Seismic Reflection and Refraction Surveys</u>

One advantage of this technique is the abundance of existing data. Numerous petroleum companies have performed seismic surveys in the WIPP area and several other surveys were performed during site selection (Powers et al. 1978; included in this compliance application as Appendix GCR). This data can be used as a reference to detect changes by comparison with new data. The quality of the data is good for lower structures but is not as useful above the 3,000-foot (914-meter) level (Appendix GCR).

Seismic surveys are nonintrusive and require no permanent devices to be installed at the site. Seismic surveys are relatively inexpensive.

#### MON.6.2.2 <u>Disadvantages of Seismic Reflection and Refraction Surveys</u>

Basic disadvantages of this technique include data quality and interpretation. This technique is sensitive to noise and equipment set-up. The data must be electronically processed,

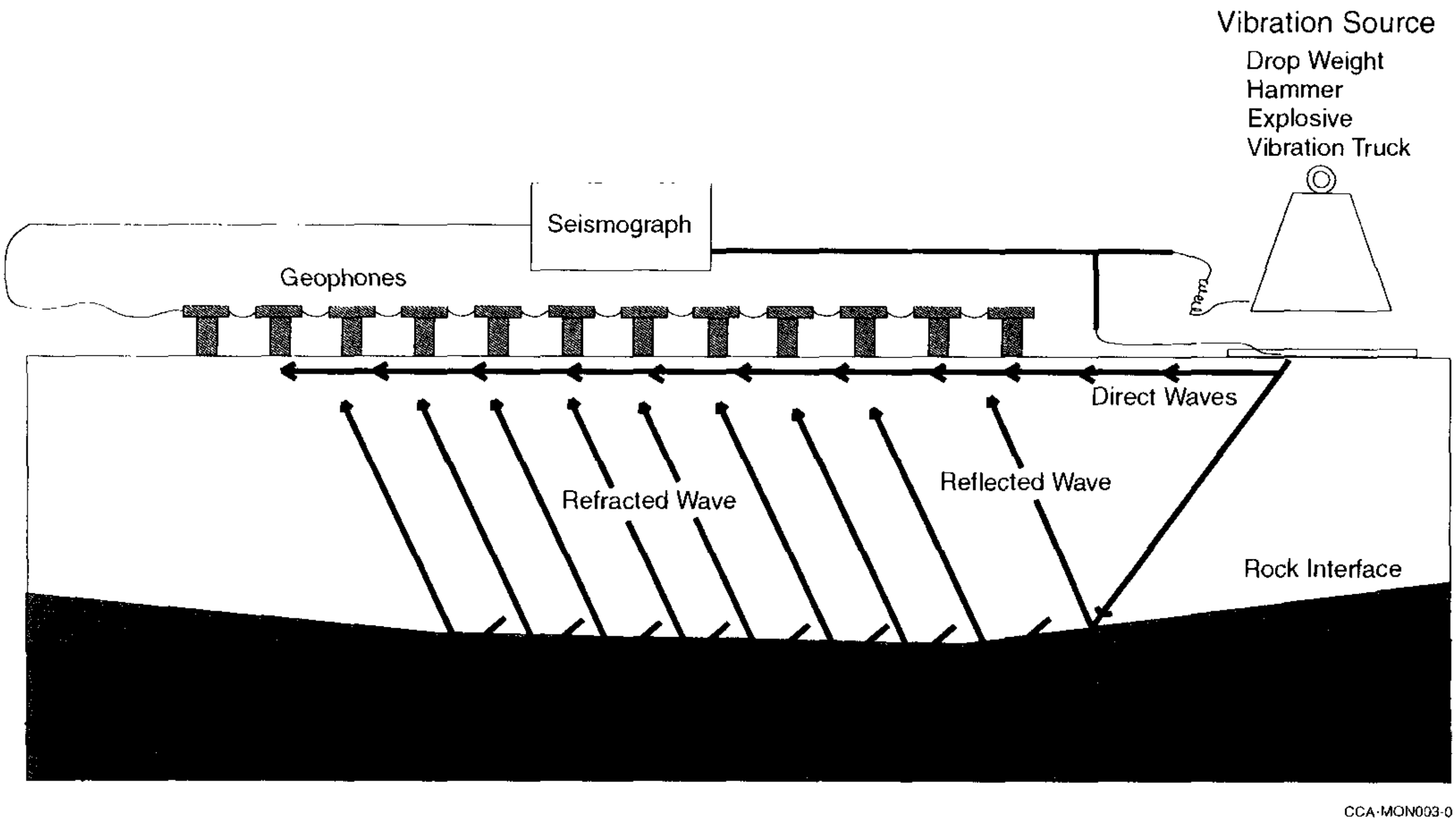


**Figure MON-6. Seismic Reflection and Refraction Survey Concept**

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conditioned, and interpreted by an experienced geologist. Interpretation is an art form and no two interpretations are the same (Griswold 1977). This can create repeatability errors if the surveys are repeated on the same geology. The results are usually compared to core samples to verify the interpretation and validate the results.

Seismic surveys use equipment that allows for many variations in how data are collected. For comparison reasons, surveys must be performed using similar equipment set-ups, that is, array spacings, line locations, and data conditioning. Any variations in the technique and equipment must be accounted for in the interpretation of the data to ensure that changes caused when different equipment is used for repeated surveys are not interpreted as geological changes.

Relatively thin strata and layers of similar densities cannot be distinguished. Because the technique is based on wave velocities, layers of material that may have different chemical and geological characteristics, but similar velocity components, cannot be differentiated.

MON.6.2.3 Past Seismic Reflection and Refraction Survey Work

During the siting process for the WIPP, several geophysical techniques were used to gather geological data that would identify a suitable site location.

From 1976 to 1978, SNL conducted three surveys totaling 79 line miles (127 kilometers) of data, of which 72 line miles (116 kilometers) were over or near the WIPP site (Hern et al. 1978). The first survey consisted of three lines totaling 24.98 line miles (40.47 kilometers) of conventional petroleum style data and was collected from petroleum companies. The other two surveys were conducted using short geophone spacing and high signal frequency for better shallow field resolution above 4,000 feet (1,220 meters) (Appendix GCR). One of these surveys totaled 47.04 line miles (67.65 kilometers) involving 13 lines. The third survey included 7.5 line miles (12 kilometers) of profiling run along crossing lines through the site (Griswold 1977; Hern et al. 1978).

Approximately 189 line miles (304 kilometers) of older (1950s to 1960s) seismic surveys performed by Shell Oil Co. were purchased from a brokerage firm (G.J. Long Associates 1976). Exxon allowed 196 line miles (315 kilometers) of their data to be viewed at their office, Amoco allowed 513 line miles (825 kilometers) of data to be viewed (G.J. Long Associates 1976). This data were considered proprietary and could not be distributed to other sources. All of the listed data were gathered and interpreted during 1976 (Griswold 1977). Results of the data were used to map the geological layers around the WIPP site. These maps are found in WP 02-9, FSAR Section 2.7 (DOE 1990).

In 1976, attempts were made to perform a high-resolution shallow survey using weight drop techniques. This survey produced data that was not interpretable when compared to known geological information (Hern et al. 1978).

In 1979, an extensive seismic survey was performed that profiled lines directly over the WIPP site boundaries in north-south and east-west patterns. The north-south lines were spaced at 0.25-mile (0.4-kilometer) intervals and the east-west lines were spaced 0.5-mile (0.8-kilometer) apart in Zone 2. In the areas between Zones 2 and 3, the lines were spaced farther apart. The north-south lines were separated by 0.5-miles (0.8-kilometers) and the east-west lines were spaced at one mile (1.62 kilometers). This survey used the same basic parameters as the original Sandia National Laboratories (SNL) survey with closer line spacing. The intent was to improve the accuracy of the data above the Salado.

### MON.6.2.4 Current Seismic Reflection and Refraction Work

No seismic surveys are being performed.

### MON.6.2.5 Define Uses for Seismic Reflection and Refraction Surveys in Postclosure Monitoring

The seismic method determines the difference in geology by measuring the velocity of a wave through the rock. Any physical change in the rock is accompanied by a corresponding change in its velocity. Seismic surveys can be used to map the repository at various times. The specific depths and densities of various formations can be mapped and compared to data generated in the future to evaluate the repository performance. Changes in the strata, such as changes in aquifer depth and strata density changes, can be determined.

After the repository is sealed and the facility is decommissioned, a seismic survey could be performed over the repository and surrounding area. This survey could be performed to provide good resolution above and below the repository. The survey results and raw data could be documented and all interpretations of the data could be documented. The results and data could be archived so baseline data can be used for comparison to future seismic data if the need arises. The baseline data will help identify changes in the geology surrounding the facility that could help determine if the repository performance is acceptable. The survey could be performed after closure and will not be resurveyed unless new data are required.

The following are requirements for seismic monitoring uses in postclosure monitoring.

- Archive data in at least two permanent formats,
- Line surveys will be referenced to benchmarks in the subsidence network,
- All data reduction programs will be included in the archive data,
- The exact location for the survey will be in accordance with the recommendation of an experienced geologist, and

- Research will be conducted to identify methods to improve repeatability in geophone placement.

### *MON.6.3 Gravitational Surveys*

The gravity survey method maps small variations in the earth's gravitational field. These variations result from mass and density difference in the subsurface lithography of the earth's crust. Interpretation of the data from a gravity survey can detect structural displacement in the strata (Barrows et al. 1983). The survey is performed by using a gravimeter. The instrument measures the gravity intensity at a point. The data is expressed in milligal, where a gal is an acceleration of 1 centimeter per square second. Standard equipment is accurate to within a tenth of a milligal.

#### MON.6.3.1 Advantages of Gravitational Surveys

This technology is helpful in determining the depth and area of various geological anomalies. In itself, gravity surveys are not concise, but aid the researcher in determining areas (anomalies) that should be explored using other geophysical techniques to determine the specifics of the anomaly.

The gravity survey is nonintrusive and relatively inexpensive when compared to other geophysical monitoring techniques.

#### MON.6.3.2 Disadvantages of Gravitational Surveys

Gravity surveys do not provide the type of information that allows a geologist to determine the exact geological description and location of the strata surveyed.

This technique is very dependent on placement of the gravimeter. Placement errors can cause variability in results if the survey is repeated. For repeatability, exact placement of the gravimeter must be recorded and verified. This variation is not as pronounced when the results are mapped over a large area.

The data from the gravimeter is sensitive to surface structure, elevation, geographic latitude, and solar and lunar tides (Barrows et al. 1983). Corrections must be made for the terrain and usually cause an error of $\pm$ 0.3 milligal (U.S. Department of the Interior [DOI] 1981). Surveying data point position and altitude is half the effort of the gravity survey. This method is prone to human error because manual recording is used. The data is often edited by reviewing the data and deleting any suspected transcription errors.

#### MON.6.3.3 Past Gravitational Survey Work

During the siting phase a regional gravity control was purchased in 1976, from a geophysical company (Griswold 1977, DOE 1983). Over 3,000 miles (4,800 kilometers) of gravity data were collected in the area as part of various hydrocarbon exploration surveys (Westinghouse Electric Corporation (WEC) 1990, Final Safety Analysis Report (FSAR) 2.7-27). Also, two gravity surveys, the main site and the reconnaissance profiles, were conducted by SNL. Three smaller areas within the main site survey were resurveyed in greater detail to provide information on suspected anomalies.

The main site survey covered approximately 8.5 square miles (13.7 square kilometers). The lines were spaced 0.6 miles (0.27 kilometers) apart and ran north-south with the stations spaced at 0.18-mile (0.09-kilometer) intervals (Barrows et al. 1983). During this survey, an anomaly was discovered and a borehole was drilled in that area. This area was surveyed in greater detail and covered an area 1,164 feet by 679 feet (355 meters by 207 meters). The stations were spaced in a grid 97 feet (30 meters) apart. Two other smaller areas were resurveyed to provide enhanced detail.

These data were used to detect anomalies in the strata and develop an interpretation of the disturbed zone. However, the disturbed zone data was inconclusive (Barrows et al. 1983). Areas surveyed detected some karst development. A gravity contour map of the WIPP site areas surveyed is found in Barrows et al. (1983).

MON.6.3.4 <u>Current Gravitational Survey Work</u>

No gravitational survey work is currently being performed by the DOE.

MON.6.3.5 <u>Define Uses of Gravitational Surveys for Postclosure Monitoring</u>

Gravity survey data could be included in the baseline database. All past surveys could be included along with extensive documentation defining the equipment, procedures, and data collection and processing techniques used. Surveys could be performed over the repository after closure and decommissioning, to provide baseline data for the repository. The original gravity survey data will not include the influence of over 6 million cubic feet (170 thousand cubic meters) of waste, so a new survey would be needed to provide a baseline after closure.

### *MON.6.4 Electromagnetic Conductivity Surveys*

The term electromagnetic conductivity is used by many geological companies to describe various geophysical equipment. For this report, the term is defined as a method that measures subsurface conductivity by low-frequency electromagnetic induction. This method uses a coil placed on the surface that transmits electromagnetic pulses that induce eddy current loops in the layered strata below the transmitting loop. The induced loop currents are in theory directly proportional to the resistance of the strata. The induced current produces a secondary field current that can be sensed by a receiving coil placed a fixed distance from the transmitting coil. The reading is a bulk measurement of conductivity of the strata directly below the transmitting loop to the effective depth of the instrument. The instruments effective depth is related to the distance between the transmitting and receiving coils. The electromagnetic system usually measures conductivity of the materials in millimhos per meter and is easily converted to resistivity. Conductivity is the reciprocal of resistivity.

The electromagnetic system determines the conductivity of the strata that is related to the soil and rock geophysical and geochemical properties. Properties such as porosity, permeability, concentrations of colloids and dissolved electrolytes in the pores, and conductive minerals all influence conductivity, but the most influential factor is water content. Because water is the main factor, aquifers and brine pockets can be detected. Pipes, waste containers, metallic debris, and wire lines can also be detected.

Electromagnetic systems can be used to profile and map strata. Both stationary and mobile systems are available. Mobile systems are capable of taking continuous readings. A diagram of the basic system configuration is shown in Figure MON-7.

MON.6.4.1 Advantages of Electromagnetic Conductivity Surveys

The electromagnetic method is nonintrusive and can detect brine occurrences, strata layers with differing physical properties, and aquifers. Mapping of an area can be compared to subsequently acquired data to determine changes such as brine movements. The depth and area of brine pockets can be determined which can then be used to estimate the volumes of the pockets. Electromagnetic surveys may be used to locate waste after placement.

The electromagnetic method does not require ground contact and the measurements can be taken continuously. Methods of this nature have good repeatability. Measurements can be made at ground level or from aerial surveys.

MON.6.4.2 Disadvantages of Electromagnetic Conductivity Surveys

Electromagnetic technology falls short in data interpretation when a highly resistive layer is sandwiched between two highly conductive layers. Strata can have the same relative conductivity but be entirely different geologically. This method is not concise enough to be a stand-alone method, but can be used along with other geophysical techniques to interpret the strata.

The results can vary with ground moisture content. Results after substantial rains are significantly different than those performed after prolonged droughts. Interpretation of the data must account for these variations.

MON.6.4.3 Past Electromagnetic Conductivity Survey Work

Several electromagnetic type surveys were performed by SNL. One survey was initiated to map brine occurrences in the strata above and below the repository. The survey measured 36 locations in a 0.9- by 0.6-mile (1.5- by 1.0-kilometer) grid directly over the repository. Two other measurements were made, one at the WIPP-12 borehole and the other at the DOE-1 borehole. A calibration measurement was made at ERDA-9. The final interpretation of the survey data details brine occurrences. These results correlated well with the depths of the brine occurrences found at WIPP-12 and ERDA-9 (Earth Technology Corporation 1988).

When comparing the results of electromagnetic survey data with borehole logs, the accuracy of determining the depth to brine is better than 246 feet (75 meters) at depths between 3,280 to 4,920 feet (1,000 to 1,500 meters).

Aeromagnetic survey maps are available from the U.S. Geological Survey (Map GP-861, Carlsbad/West Texas) and Aero Service Library (No. 43-6, Carlsbad/West Texas) (Elliot Geophysical Co. 1976).

#### MON.6.4.4 Current Electromagnetic Conductivity Survey Work

No electromagnetic work is currently being performed.

#### MON.6.4.5 Define Uses of Electromagnetic Conductivity Surveys for Postclosure Monitoring

Electromagnetic surveying is capable of detecting water or brine occurrences, and can differentiate layers with varying physical properties. This technique could be used to monitor the facility after closure to determine if brine has migrated into the shafts, boreholes and/or repository.

The performance of the shaft, borehole seals, and boreholes could be monitored to determine if they are maintaining the isolation between the aquifers in the Rustler Formation. The repository could be mapped directly after the repository is sealed and included in the baseline data to be used for comparison at a later date.

### *MON.6.5 Resistivity Surveys*

The resistivity method is similar in nature to the electromagnetic method. Resistivity measures the resistance of the rock and electromagnetic measures the conductance. Resistance is the reciprocal of conductance. The resistivity of the rock and soil is influenced by the same factors listed in the previous section for conductivity. By varying the electrode spacing geometries and currents, different parameters can be measured. Two specific methods used during WIPP siting are called Schlumberger sounding and gradient array profiling.

The resistivity method uses four sets of electrodes on the surface, spaced in a specific geometry. Two electrodes are energized to create a current through the strata between the electrodes. The second pair of electrodes measures the potential produced from the first pair. The strata's resistivity can be calculated from the potential and electrode geometry and spacing.

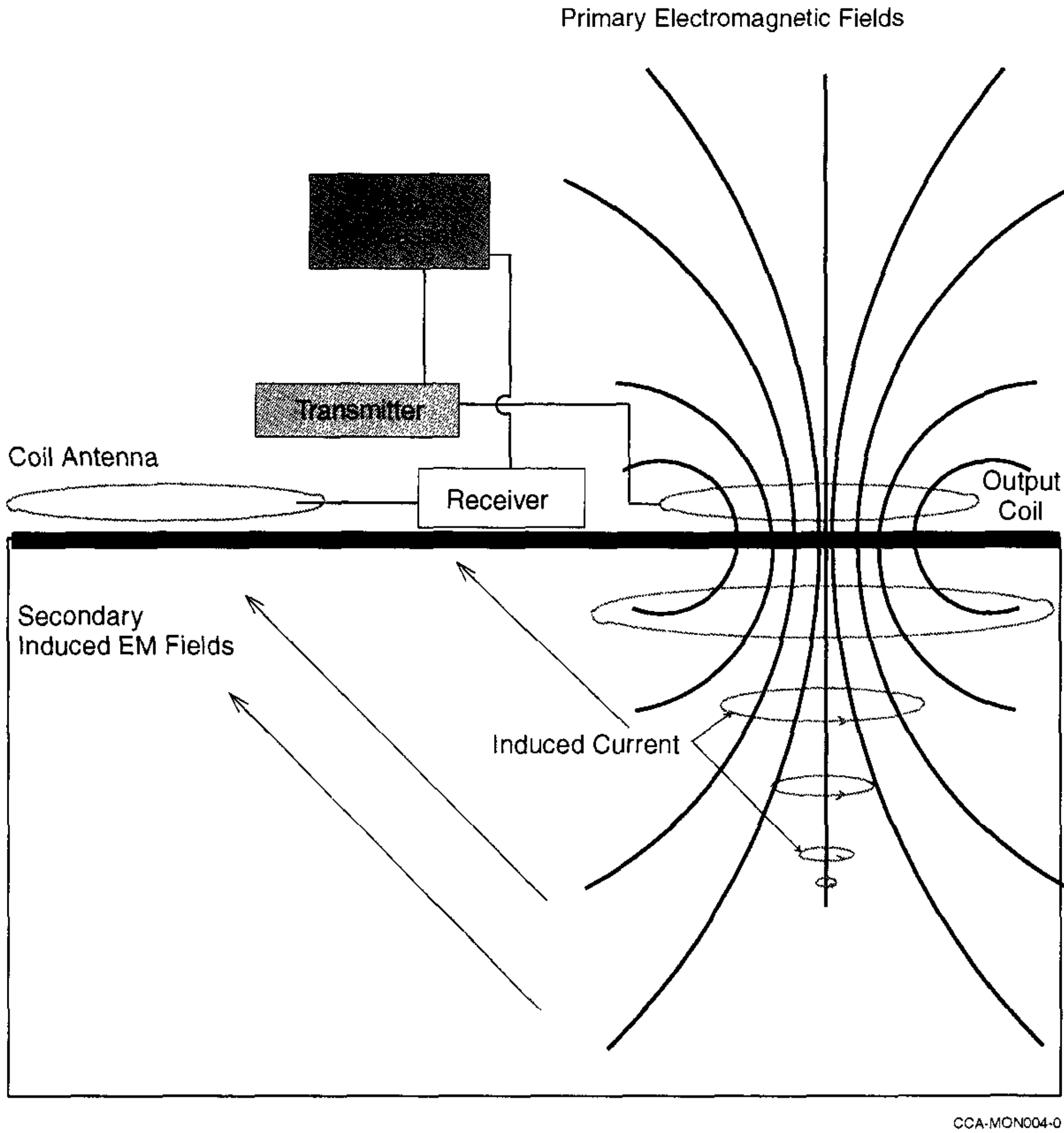


**Figure MON-7. Electromagnetic Survey Technique**

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As with the other types of geophysical monitoring methods, resistivity measurements can be used to perform sounding and profiling. Profiling maps the changes in the subsurface resistivity horizontally. Sounding can detect vertical changes in subsurface resistivity. The interpretation of the results can be used to determine the depth and thickness of geologic layers of different resistivity. This method can detect soil thickness and depth to aquifers or brine layers. A diagram describing the basic system configuration is shown in Figure MON-8.

### MON.6.5.1 Advantages of Resistivity Surveys

The gradient array method is a relatively simple method. The electrodes are separated at large distances which enables economical mapping of large areas.

The advantages of this method are identical to the electromagnetic method.

### MON.6.5.2 Disadvantages of Resistivity Surveys

Variations in placement will give differing results if the survey is repeated in the same area. The resistivity surveys require direct ground contact and cannot be performed continuously. The condition of the surface layer can affect the results because variation in the soils moisture content can be detected. Measurements performed shortly after rains will be significantly different than measurements taken after prolonged droughts. However, this can be accounted for in the interpretation of the results. Resistivity also has the same disadvantages as the electromagnetic method.

### MON.6.5.3 Past Resistivity Survey Work

Extensive resistivity surveys were conducted during the siting of the WIPP from 1976 to 1978. Areas around suspected breccia pipes and sinks (off-site) were surveyed to determine if resistivity surveys could be used to detect these structures within the WIPP site. All zones of the WIPP site were surveyed. Mining Geophysical Surveys, Inc. performed 53 Schlumberger array soundings and approximately 391 line miles (629 kilometers) of gradient array profiling (9,880 measurements) (Elliot Geophysical Co. 1977).

### MON.6.5.4 Current Resistivity Survey Work

No resistivity work is currently being performed.

### MON.6.5.5 Define Uses of Resistivity Surveys for Postclosure Monitoring

This technology can be used along with electromagnetic techniques to gather data immediately after the repository is sealed. Both profiling and sounding would be performed to produce geological maps of the strata's resistivity. When the surveys are made, the exact locations and methods used could be carefully documented. If possible, research could be required to develop a system for electrode placement to ensure good repeatability in the surveys. This data would be documented in the baseline database for future comparison.

### *MON.6.6 Environmental Monitoring*

Environmental monitoring of the WIPP repository will be performed during the operational and decontamination-and-decommissioning periods. The C&C between the state of New Mexico and the DOE requires radiological environmental monitoring for at least five years after final facility closure. This agreement specifies that the environmental monitoring program in place during the operational phase must be continued after closure and decommissioning for at least two years, and that an abbreviated program with a limited number of radiological air, soil, water, and background samples be continued for the following three years.

The postclosure environmental monitoring program is required to include the following (DOE 1994a):

- Radiological Environmental Monitoring (first two years after decontamination and decommissioning)

  - Airborne particulate
    lo-vol sampling, eight stations
  - Vegetation
    four sites
  - Beef
    annual muscle samples if available
  - Game animals
    annual muscle samples of rabbits and quail.
  - Soil samples
    annual, multiple samples at multiple depths at six locations.
  - Surface and drinking water
    annual surface water samples from 12 major bodies of surface water in the vicinity of the site (drinking water will not exist after decontamination and decommissioning)
  - Groundwater
    annually, one sample from eight of the wells within the 16 sections boundary taken from the Culebra Dolomite.
  - Aquatic foodstuffs
    samples of catfish taken from the Pecos River and Brantley Lake and analysis annually.
  - Sediment sampling
    annual samples taken from the Hill and Indian tank and the Pecos River near Artesia and Malaga, New Mexico.

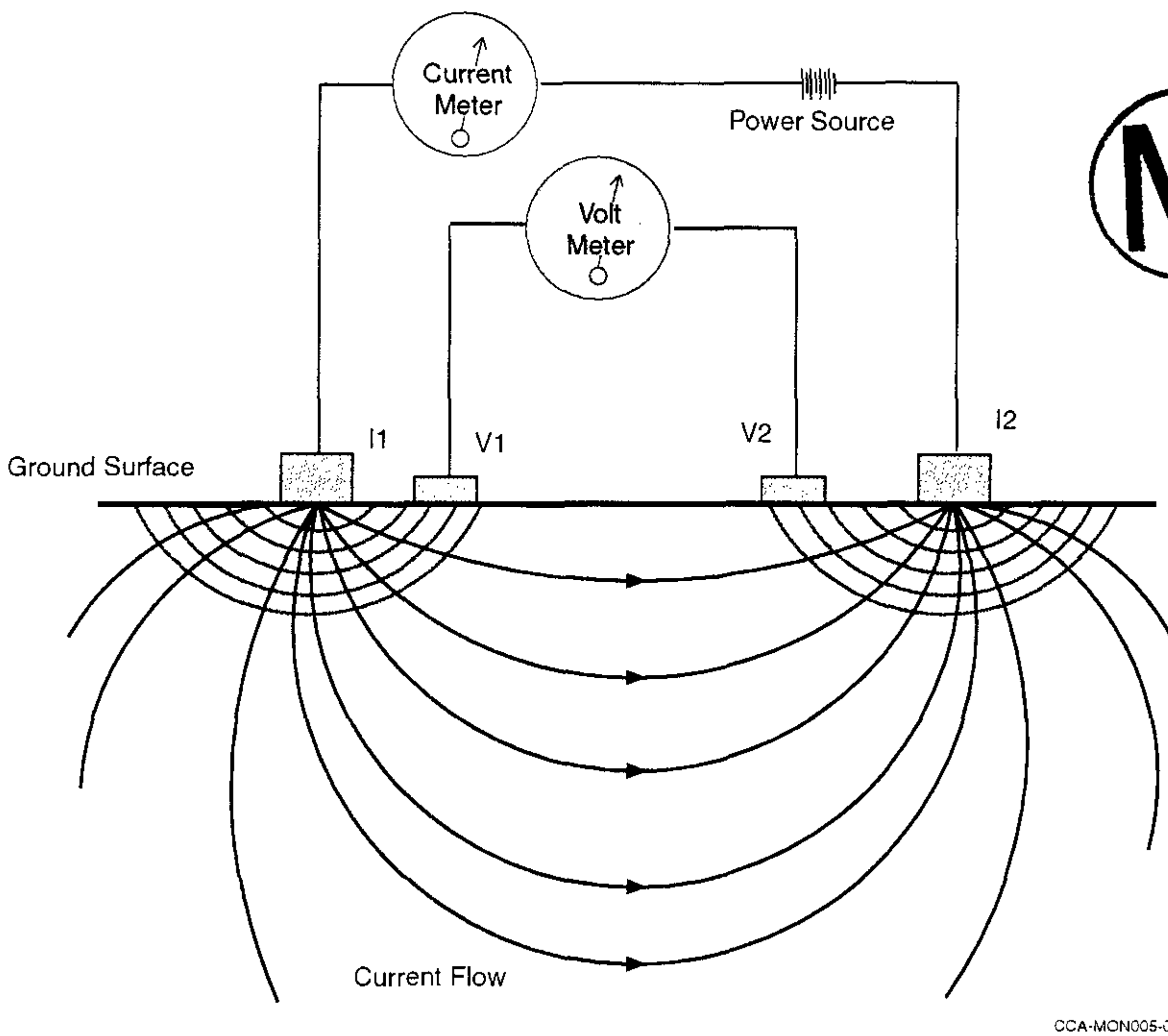


**Figure MON-8. Resistivity Survey Concept**

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- Abbreviated radiological environmental monitoring (three, four, and five years after decontamination and decommissioning).

  - Airborne particulate
    intermittent operation of the state-operated high-volume air sampling stations.
  - Soil
    four annual soil surface samples.
  - Water
    four annual well water samples.

Only the radiological environmental monitoring techniques that apply after final closure are included. Items such as effluent monitoring at the exhaust shaft were not included because they do not apply after final facility closure.

Environmental monitoring has been an ongoing program since the WIPP's inception. Baseline environmental data were gathered and reported in annual reports and an environmental monitoring plan was created. The current operational environmental monitoring plan is detailed in the *Waste Isolation Pilot Plant Environmental Monitoring Plan*, WIPP/DOE 94-024 (DOE 1994a) and the *Waste Isolation Pilot Plant Site Environmental Report for the Calendar Year 1993*, DOE/WIPP 94-2033 (DOE 1994b).

### *MON.6.7 Direct Repository Monitoring*

From earlier discussions, no proposed postclosure monitoring techniques include technologies to directly monitor the repository. This is due to the inherent difficulties imposed by the noninvasive requirement. No wiring or boreholes will be used to connect monitoring equipment in the repository to the surface.

The U.S. Bureau of Mines and commercial companies throughout the world are currently researching techniques to communicate through the strata to mine working areas using very-low frequency and ultra-low frequency electromagnetic radiation. Several companies have developed mine paging systems that use very-low frequency to warn workers within the mine using a system placed on the surface. One system can transmit messages with up to 32 characters to mobile mine pagers. This technology shows promise in remote instrumentation communication that could directly monitor the repository. It has been demonstrated in other salt mines that communication from the surface to the depth of the WIPP repository is possible.

Recently, researchers have started to investigate methods to remotely monitor the sealed rooms and panels. This work uses very-low frequency technology to link sensors and equipment in sealed rooms to the data recorder without a hardwired link. Current work is focused on communication from where the link between the transmitter and receiver is only 10 to 33 feet (3 to 10 meters).

Very-low frequency could be used to transmit data from the surface to equipment located in the repository but the problem lies in communicating the sensor data to the surface. The power required to transmit between the surface and the underground using the current technology is related to the strata conductivity, the output power at the transmitter, and the antenna design. Tests performed in actual mines used large loop antennas on the surface to transmit the signal. Tests have shown that loop diameter is more important in transmission efficiency than output power. Antennas ranging from 98 feet to over 328 feet (30 meters to over 100 meters) in diameter have been used (DOI 1991).

There are many problems that must be overcome to directly monitor the repository after closure. Some of these problems are listed below.

- Future sensor and transducer calibration would not be possible,
- Sensor longevity in the repository environment is not likely,
- Data collection and transmission power requirements could be problematic, and
- Antenna locations and sizes could pose issues with regard to other surface structures and activities.

MON.6.7.1 Sensor Calibration

Over time, most sensors, such as pressure, gas analyzer, and extensometer sensor and transducer, experience some change in resolution or drift. Any type of sensor and transducer used would need to operate for 100 years without recalibration. To overcome this problem, redundant sensors, sensor drift calculations, and accessible sensors as standards could be used to limit the induced errors. However, this would not ensure accuracy over the required time frame.

MON.6.7.2 Sensor Longevity

The sensors used for postclosure monitoring would be required to operate in a salt/brine environment for over 100 years. This imposes the biggest obstacle in direct repository monitoring. Corrosion, oxidation, and various chemical reactions would easily limit the life span to less than 50 years.

MON.6.7.3 Data Collection and Transmission Power Requirements

A power source that could operate for the time required is not currently available. Battery systems have limited shelf lives and capacities. Lithium-type batteries have the longest shelf life of the common battery types. Standard shelf lives of five to 10 years at their rated capacity is standard with some manufacturer's claiming 80-percent capacity after 15 years. Because the capacity requirements are dependent on the equipment load, the highest current requirement would occur during data transmittal. From experimental work, an estimate of at least 350 watts may be required to transmit to the surface. This can be accomplished with standard power sources for the short-term, but other currently unavailable methods of power generation would be required for the long-term.

One potential method is power transmission and retention. Power could be transmitted from the surface using ultra-low frequency energy and an antenna would intercept this energy and store it in capacitors or a special battery. Because the system could be charged for long periods of time between data transmissions, only a small amount of surface transmitted power is required. The problem with this approach is power storage.

The chemical nature of rechargeable batteries limits their life span. The effects of oxidation, outgasing, and heat damage will cause a battery to fail. The life span of most common rechargeable (lead acid, gel, and nickel cadmium) batteries is dependent on the number of recharge cycles, the rate of discharge, and charge rates. Under favorable conditions, most rechargeable batteries can last up to 10 years.

The capacitor is a device that stores energy on two plates separated by an insulator. Capacitors can be designed for this application that would last the required time frame. The problem associated with capacitors is related to power storage capability and size. In comparison, a capacitor and a battery with the same approximate volume do not have the same energy storage capacity. For example, a one-microfarad capacitor charged to 1,000 volts has 0.5 Joules of energy storage, a 500-mAh nickel cadmium (1.2 volts) of similar volume has 2,160 Joules of energy storage. A capacitor that has this energy storage potential would be extremely large (4,320 times larger).

Satellite power sources use nuclear energy to generate power. The systems are not considered off-the-shelf technology. However, work is progressing on a nuclear heat power source using (almost) off-the-shelf technology. One experimental study calls this type of power source a Powerstick (Chmielewski and Ewell 1994). This theoretical device would use a nuclear heat source and a thermopile to generate an electrical potential. The heat source is a common satellite product used to heat instrumentation. The power source is capable of producing 42 milliwatts at 15 volts initially and would degrade to 37 milliwatts at 14 volts in 10 years. These power sources could be used to slowly charge batteries and/or capacitors that would then be used for a short duration, high-demand data transmission cycle or in parallel for a higher current source.

The regulatory issues associated with nuclear power sources have not been researched. If the remotely-handled waste could supply an adequate heat source and WIPP receives remotely-handled waste, the regulatory issues may be overcome.

The nuclear and thermopile power source technology has not been proven and there is no prototype as yet. Advances in battery design and the development of this nuclear power source could eventually allow this technology to power a direct repository monitor.

MON.6.7.4 Antenna Location and Size

The size of the antenna may pose a problem in the mine setting. If the antenna is placed inside a room, diameters are limited to a maximum of approximately 328 feet (100 meters). If the antenna can be wrapped around a pillar, the antenna would have a radius of approximately 164 feet (50 meters) but diameters between 32.8 feet and 328 feet (10 meters and 100 meters) would require special provisions. Also, the effects of the metal in the room will increase the power requirement. These problems can be overcome and experimentation would be needed to verify the effectiveness of the antenna design.

From current technology, no known system is currently available that could be used to directly transmit data to the surface without a hardwired link. Extensive research and development is needed to develop such a system; however, the systems longevity will be suspect, since actual long-term testing could not be accomplished and new technologies are rarely foolproof. For this reason, direct repository monitoring is not recommended at this time for postclosure monitoring.

### *MON.6.8 Conclusion*

There is no single geophysical technical exploratory technique that can determine the condition of the surveyed strata. Several techniques are used to gather data to assess the geological structure that is being examined because interpretation of one technique often uses data from another. For this reason, no single technique could be used to fully assess the repository's condition. One technique can be used as an identifier to alert that a condition may exist and other techniques can be used in unison to assess and validate the condition.

From the review of geophysical survey techniques, the best current monitoring technology that can be used for a postclosure monitoring identifier is subsidence. This method is the most practical because it is a simple, repeatable, low-cost, low-maintenance, low-technology approach to monitoring the repository. This method should be used as a primary monitor technique for determining that a possible repository performance problem exists. Other techniques can then be utilized to determine the cause of the problem.

A combination of seismic, electromagnetic, resistivity, and gravitational surveys can be used to assess repository performance. However, it is not practical to perform these on a regular basis. These techniques are also not needed if there is good confidence that a performance-related event will not occur. For this reason, an initial collection of surveys could be compiled and used as a standard to assess future data and perform subsidence monitoring to forewarn of changing conditions that may significantly affect repository performance.

## MON.7 Postclosure Monitoring Program Summary

Physical, chemical, economical, and technical factors have been included in the conceptual approach to designing a practical, yet effective, postclosure monitoring system. The needed information can be obtained from a monitoring system composed of a subsidence network, a monitoring program, a baseline database, a closure review study, and a subsidence data study.

The following summarizes the postclosure monitoring program.

- The DOE will create a baseline database that includes data from developmental and operational phase activities.

- The DOE will perform a subsidence data study.

- The DOE will compile subsidence predictions and include any performance assessment- developed scenarios of repository performance which fall outside the baseline subsidence predictions. The DOE will develop proper benchmark locations over the repository. The subsidence predictions will be developed from the information available in the *Backfill Engineering Analysis Report (BEAR)* (WEC 1994c) and from any additional information provided by the performance assessment.

- The DOE will create a subsidence network over and around the facility.

- The DOE will perform a closure review study.

- The DOE will perform the following surveys to establish baseline data for the baseline database.

    - Seismic survey over the waste panels after final facility closure (one time).
    - Resistivity survey over the waste panels after final facility closure (one time).
    - Electromagnetic survey over the waste panels after closure (one time).
    - Gravitational survey after final facility closure (one time).
    - Subsidence survey (throughout the program lifetime).
    - Obtain and archive core samples from previous core work (one time).

- The DOE will initiate the monitoring program after closure. The DOE will perform periodic leveling surveys of the subsidence network and develop a schedule for future surveys. The DOE will perform the radiological environmental monitoring program for two years and the abbreviated program for an additional three years.

- The DOE will compare leveling survey data to expected results.

- The DOE will perform periodic reviews at least every two years during the monitoring program to evaluate the monitoring schedule.

- The DOE will perform maintenance on RCRA wells, replacing casings as required or every 25 years until monitoring ceases. The DOE will monitor in accordance with the postclosure monitoring schedule and postclosure monitoring plan requirements.

- The DOE will perform maintenance on subsidence network as required (determined during the leveling surveys).

This monitoring concept is based on current technologies and data for monitoring repository performance. Future monitoring during the repository development and operational phases may provide data that lead to the conclusion that postclosure monitoring will not be relevant or may identify new parameters that must be monitored.

The monitoring techniques specified in this report can be used to meet the requirements in the current regulations governing the facility and to monitor performance of the facility. This concept provides for a reliable database against which future monitoring results can be compared.

## MON.8 QA and Quality Control Requirements

Various QA and quality control requirements exist for the DOE and many QA and quality control programs are in place. The WIPP is a DOE facility and as such has specific DOE guidelines for QA and quality control management. These guidelines for WIPP can be referenced in the *Quality Assurance Program Document,* CA0-94-1012, 1996, Revision 1.0. The DOE has agreed to adopt QA and quality control guidance from the American Society of Mechanical Engineers Nuclear Quality Assurance (NQA)-1, NQA-2 Part 2.7, and NQA-3. The EPA also has imposed QA and quality control requirements for the data management and the postclosure monitoring plan, specifically requirements in 40 CFR § 268.6(b (4) and 40 CFR § 268.6 (c) (1 through 5). The scientific advisor also has a QA and quality control program that is used for data collection that impacts postclosure monitoring.

For this postclosure monitoring report, all the current and future programs will be conducted under the applicable QA and quality control qualifications described in Chapter 5.0.

Other QA issues are associated with 40 CFR § 268.6 requirements. This regulation requires the postclosure monitoring plan to contain detailed records of the postclosure monitoring system and data collection and recording procedures. Specifically, "All sampling, testing, and analytical data must be approved by the Administrator and must provide data that is accurate and reproducible" (40 CFR § 268.6(c)(5)(i)) and, "A quality assurance and quality control plan addressing all aspects of the monitoring program must be provided to and approved by the Administrator" (40 CFR § 268.6(c)(5)(iii)). The DOE's quality control description for the WIPP has been used in all applicable postclosure monitoring program development and shall be used for all future actions within the postclosure monitoring program.

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# ATTACHMENT

Attachment 1: MONPAR (Monitoring Parameters)