ATTACHMENT A
TO
APPENDIX MON 2004

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ACRONYMS

BEAR	Backfill Engineering Analysis Report
DOE	Department of Energy
DOI	Department of Interior
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
NGS	National Geodetic Survey
QAPD	Quality Assurance Program Description
SNL	Sandia National Laboratories
S-Caps	Subsidence Monuments
WEC	Westinghouse Electric Corporation
WIPP	Waste Isolation Pilot Plant

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POSTCLOSURE MONITORING

MON-A-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-A-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-A-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 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-A-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-A-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-A-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 (BEAR)* (WEC 1994b). 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	
35E angle	0.3-foot (0.09-meter) subsidence
25E 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-A.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-A-6.1.6 Future Work on Subsidence Monitoring

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-A-6.1.7 Define Use of Subsidence Surveys for Postclosure Monitoring

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-A-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-A.6 details the basic seismic surveying technique.

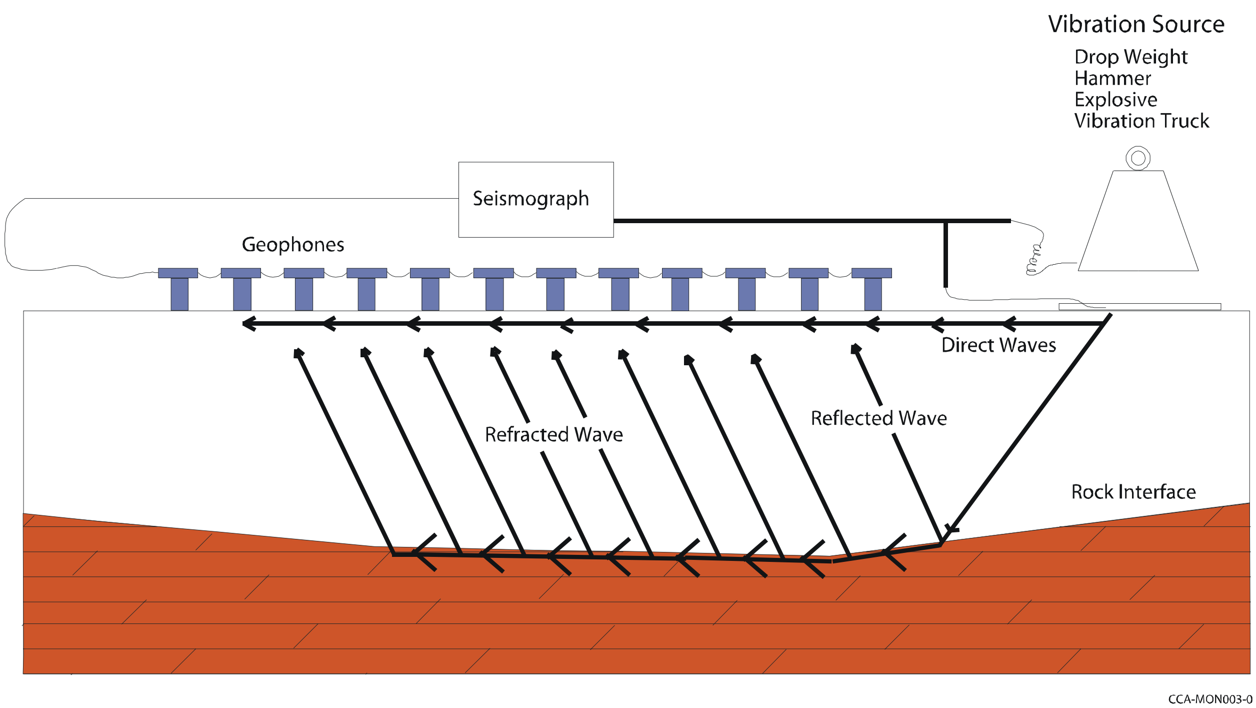

Figure MON-A.6. Seismic Reflection and Refraction Survey Concept

MON-A-6.2.1 Advantages of Seismic Reflection and Refraction Surveys

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-A-6.2.2 Disadvantages of Seismic Reflection and Refraction Surveys

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, 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-A-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-A-6.2.4 Current Seismic Reflection and Refraction Work

No seismic surveys are being performed.

MON-A-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-A-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-A-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-A-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 ± 0.3 milligal (DOE 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-A-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-A-6.3.4 Current Gravitational Survey Work

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

MON-A-6.3.5 Define Uses of Gravitational Surveys for Postclosure Monitoring

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-A-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-A.7.

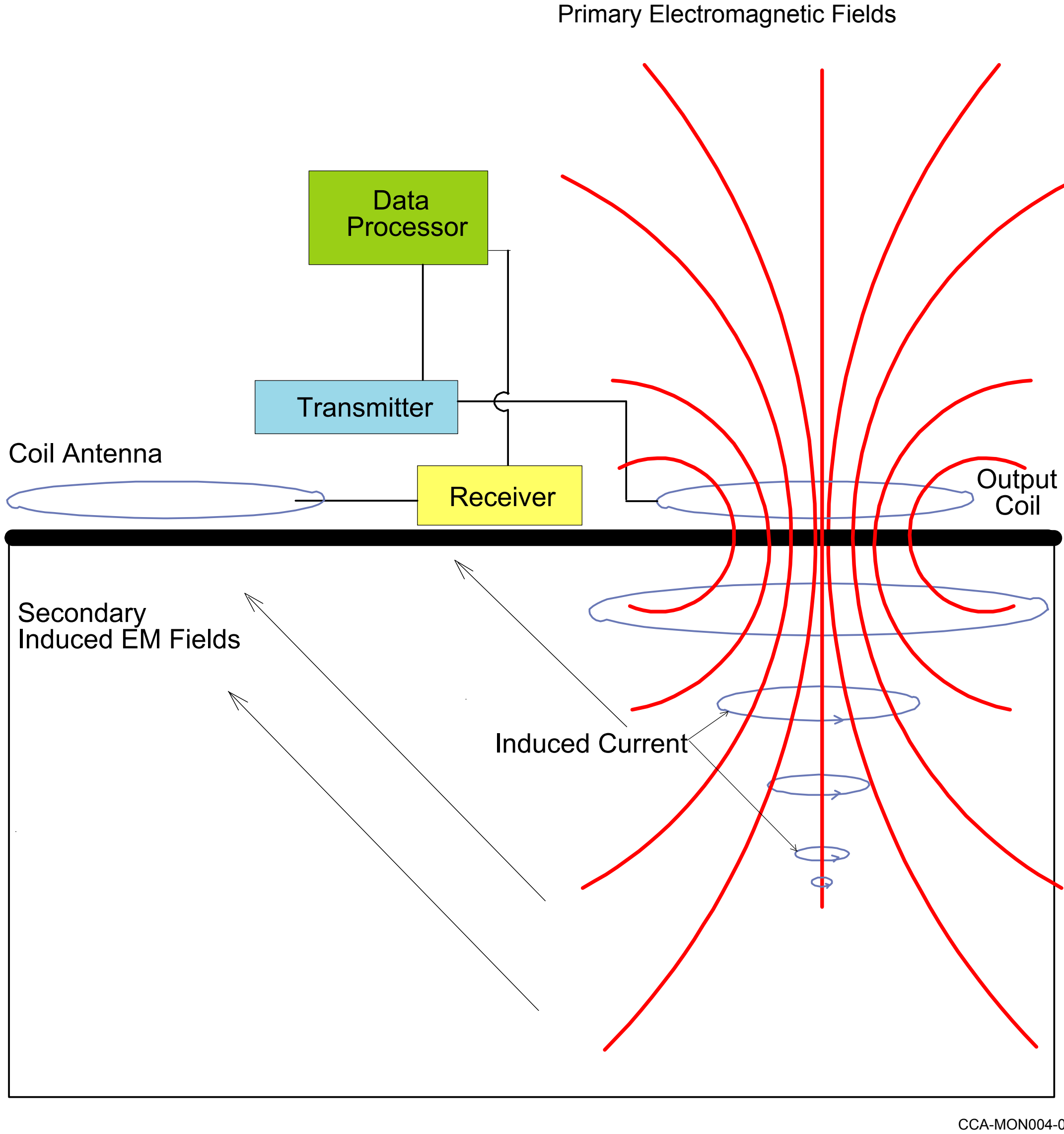

Figure MON-A.7. Electromagnetic Survey Technique

MON-A-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-A-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-A-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-A-6.4.4 Current Electromagnetic Conductivity Survey Work

No electromagnetic work is currently being performed.

MON-A-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-A-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.

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-A.8.

MON-A-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-A-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-A-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).

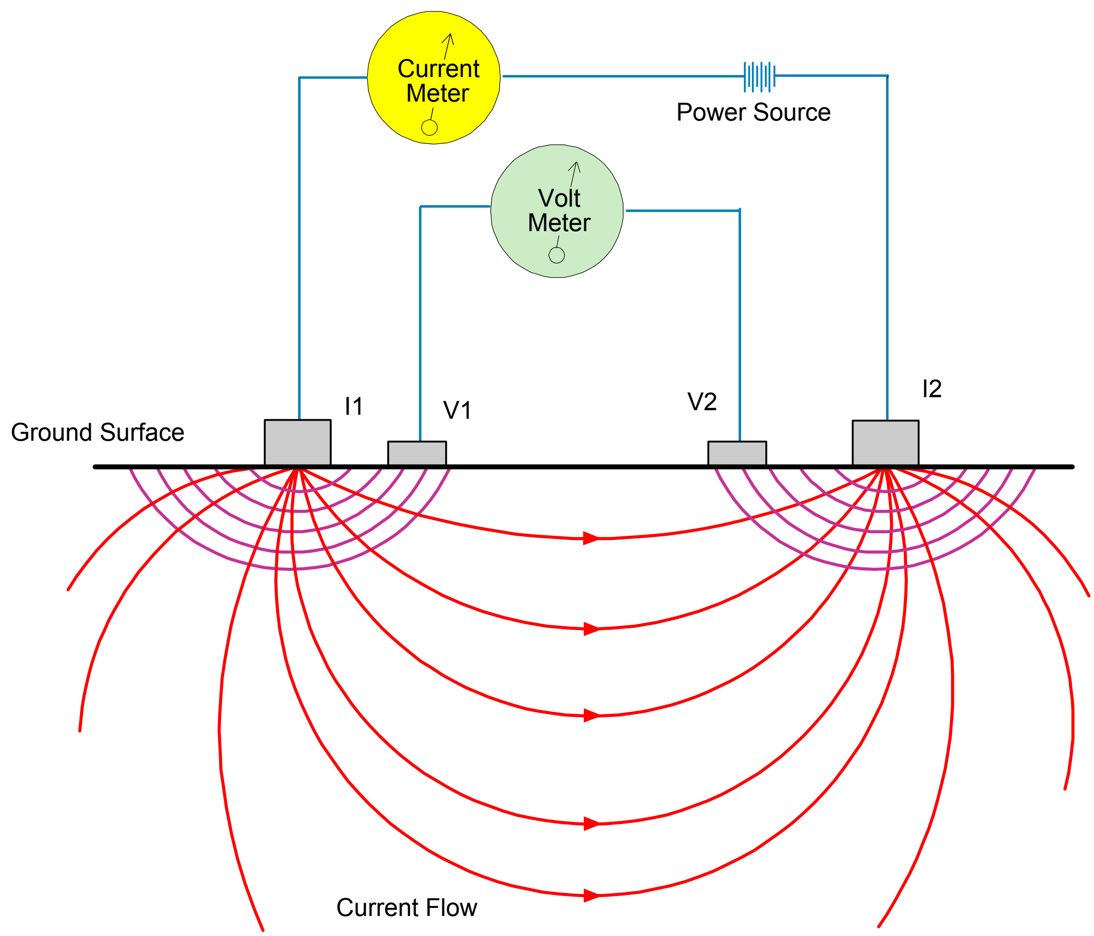

Figure MON-A.8. Resistivity Survey Content

MON-A-6.5.4 Current Resistivity Survey Work

No resistivity work is currently being performed.

MON-A-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-A-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.
- 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-A-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-A-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-A-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-A-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-A-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-A-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-A-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 1994b) 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.

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