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Large-Scale Dynamic Compaction Demonstration Using WIPP Salt: Fielding and Preliminary Results

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Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

SF2900Q(8-81)

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Distribution
Category UC-721

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ABSTRACT

Large-scale dynamic compaction of natural salt has been successfully demonstrated. This report details the procedures used and documents overall activities. About 40 m^3 of salt was compacted in three lifts by dropping a 9,000-kg weight 15 m in a systematic pattern to achieve an input energy of three times Modified Proctor Energy. One weight percent water was added to the relatively dry mine-run WIPP salt to enhance compaction. The compacted mass density averaged 90% of that of natural, intact WIPP salt and *in situ* nitrogen permeabilities averaged 9E-14 m^2. This unique demonstration shows the viability of dynamic compaction as a potential technology for placement of salt seal components within WIPP shafts and provides compacted salt parameters needed for design and performance assessment.

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FIGURES

TABLES

ACRONYMS

A/D	analog to digital
Btu	British thermal unit
cm	centimeter
DOE	Department of Energy
EPA	Environmental Protection Agency
ES&H	environmental safety and health
ESE	east southeast
F	Fahrenheit
ft	feet
in	inch
kg	kilograms
lb	pounds
LSST	large-scale seal test
m	meter
MPE	Modified Proctor Energy
mph	miles per hour
NE	northeast
NW	northwest
WNW	west northwest
SE	southeast
PA	performance assessment
PC	personal computer
PI	principal investigator
psig	pounds per square inch gauge
QA	quality assurance
QAP	quality assurance procedure
RAM	random access memory
SNL	Sandia National Laboratories
SOP	standard operating procedure
SWCF	Sandia WIPP Central Files
TDD	technology development demonstration
TOPs	technical operating procedures
WIPP	Waste Isolation Pilot Plant

NOTE

Both English and Standard International (SI) units are used in this report. The construction industry uses English units during preliminary considerations and design, whereas the scientific community uses SI. In general, the engineering information is retained in English units and SI units are used in the text where the conversion makes sense. Laboratory and field measurements of density, permeability, water content, and discussion of technical results are all in SI units.

1.0 INTRODUCTION

Reconsolidation of crushed rock salt is a phenomenon of great interest to programs studying isolation of hazardous materials in natural salt geologic settings. Of particular interest is the potential for disaggregated salt to be restored to nearly an impermeable state. For example, reconsolidated crushed salt is proposed as a major shaft seal component for the Waste Isolation Pilot Plant (WIPP) Project. The concept for a permanent shaft seal component of the WIPP repository is to densely compact crushed salt in the four shafts; an effective seal will then be developed as the surrounding salt creeps into the shafts, further consolidating the crushed salt. Fundamental information on placement density and permeability is required to ensure attainment of the design function. The work reported here is the first large-scale compaction demonstration to provide information on initial salt properties applicable to design, construction, and performance expectations.

The shaft seals must function for 10,000 years. Over this period a crushed salt mass will become less permeable as it is compressed by creep closure of salt surrounding the shaft. These facts preclude the possibility of conducting a full-scale, real-time field test. Because permanent seals taking advantage of salt reconsolidation have never been constructed, performance measurements have not been made on an appropriately large scale. An understanding of potential construction methods, achievable initial density and permeability, and performance of reconsolidated salt over time is required for seal design and performance assessment. This report discusses fielding and operations of a nearly full-scale dynamic compaction of mine-run WIPP salt, and presents preliminary density and *in situ* (in place) gas permeability results.

Current design requirements of the shaft sealing system for the WIPP are based on interpretations of federal and state regulations requiring that the seal system limit brine migration into the repository and gas or brine transport out. A long-standing assumption supporting disposal of hazardous waste in salt formations is that disaggregated salt can be reconsolidated to sufficient density to prevent excavated openings from becoming preferential pathways for transport and possible release of hazardous materials. Laboratory testing has supported this position by emphasizing reconsolidation of crushed salt, although alternative placement techniques are possible. Previously, analyses have assumed placement densities on the order of 80-85% of theoretical intact density. Because of the lack of a database on salt compaction, evaluations of seal performance and compliance with regulations have contained considerable uncertainty. Results of the study reported here greatly reduce uncertainty regarding seal performance and improve the potential for achieving regulatory compliance.

Prior to the large compaction demonstration, confidence in component model parameters needed for structural and fluid flow calculations was limited by a lack of data on *in situ* characteristics of compacted salt. Simultaneous with recent design calculations, calculations for system prioritization studies identified permeability distribution functions of the shaft salt seals as a determining parameter in the ability of the WIPP site to meet compliance requirements. As of the writing of this report, laboratory testing is in progress to determine gas permeability, moisture content, and density of compacted salt specimens produced by this demonstration. Laboratory studies may also illuminate the micromechanical processes that give rise to the reduction of void volume. Data from these laboratory tests will be used in performance assessment (PA) modeling and will be presented in a subsequent technical paper.

The remaining sections of this report present details of the large-scale dynamic compaction investigations. Subsection 1.1 introduces the WIPP setting and the Environmental Protection Agency (EPA) regulatory role. Subsection 1.2 presents preliminary compaction results which provided the justification and a technical basis for the current large-scale work. Section 2.0 describes several of the prime considerations preceding the actual compaction of salt. Logistic efforts necessary to initiate the tests were appreciable and this section discusses design and test considerations. Section 3.0 is a summary of key events occurring during compaction. Section 4.0 contains the results of the compaction test. These results are both qualitative and quantitative, including descriptions of general procedures, observations of operational events, and preliminary *in situ* gas permeability test results. Section 5.0 recaps the main conclusions of the large-scale dynamic compaction demonstration. Section 6.0 contains references. Appendix A includes edited daily logs over the duration of field activities.

1.1 Background

The WIPP facility is located in southeastern New Mexico at a depth of 650 m below surface in the Salado Formation. The Salado is a sequence of bedded evaporites, approximately 600 m thick, deposited during the Permian Period ending 225 million years ago. There are many reasons for siting a repository in thick salt formations. Perhaps the most important advantage of salt as a host for waste isolation is its ability to creep and ultimately entomb material placed in excavated openings. Other attributes of salt include its very low permeability, vertical and lateral stratigraphic extent, and tectonic stability. Creep closure also plays an important role in shaft sealing strategy. The idea of returning salt excavated as a result of developing the facility back to the underground as part of the decommissioning process has been investigated since the National Academy of Sciences first recommended salt as a host medium for nuclear waste disposal. The possibility of using compacted crushed salt as a seal component has been seriously considered for at least a dozen years. Not until recently, however, have performance measures for reconsolidating salt been investigated.

The EPA has statutory regulatory responsibility for the WIPP. A compliance certification application is being prepared by the Department of Energy (DOE) for consideration by the EPA. The application will include a design for a shaft seal system. It is recognized that a shaft seal would not be installed until disposal is complete (30 years or perhaps much longer). Nonetheless, assurance that a viable seal system can be installed must be demonstrated in the compliance submittal. Hundreds of vertical feet of crushed salt compacted against the intact Salado Formation salt in the WIPP shafts is proposed as a major material in the multicomponent WIPP shaft seals.

Demonstration of potential construction technology and performance of compacted salt is essential for the EPA to render a favorable compliance determination.

1.2 Initial Technology Demonstration

The unique work reported here follows an earlier technology development demonstration (TDD). Execution of the large-scale seal test (LSST) was justified by programmatic needs and by early success using a dynamic compaction technique. Vertical dynamic compaction was chosen from several commercially available options, such as vibrating or roller compaction, because it is a simple and effective technique for compacting noncohesive soils such as sands and also appears amenable for use in the shafts. A synopsis of the initial, relatively small-scale tests is presented in this section. A more detailed summary is given by Hansen et al. (1995).

Preliminary compaction demonstrations were conducted within the confines of the SNL Tech Area III Drop Tower Facility as a "technology development demonstration." A TDD is a SNL procedure allowing for rapid evaluation of a technology to determine feasibility before implementing the rigorous quality assurance (QA) procedures required for data used to support compliance. Dynamic compaction in the preliminary TDD was achieved by systematically dropping a cylindrical tamper into a chamber containing mine-run WIPP salt. The steel compaction chamber (1.2 m diameter and 1.8 m height) was specifically designed and built for these tests. Two TDD tests were completed. The first test used mine-run salt with no water added; 1.0 wt % water was added in the second test. More compactive energy was imparted in the first test than in the second test, as discussed later.

A clockwise tamping sequence illustrated in Figure 1 was used in the TDD investigations. The first three drops were in the center, followed by moving to the 12 o'clock position and proceeding clockwise around the loop. Each sequential drop position overlapped the previous one by approximately one radius. The tamper used in the technology demonstration was a right circular cylinder weighing 890 kg; it had a 0.4-m diameter and a 1.1-m height. Drop height was 9.1 m (30 ft) and drop accuracy was within 2.5 cm (1 in) of the intended location. The first TDD test imparted three times Modified Proctor Energy (MPE) to each lift. One Modified Proctor Energy is 56,200 ft-lb/ft^3 (where the volume refers to the area directly below the tamper) and is equivalent to the compactive effort exerted by the largest piece of equipment commonly used in construction. Section 2.2 discusses calculation of the compaction energy and provides SI conversion units. The second TDD test applied 2 MPE per lift.

The first TDD compacted mine-run salt containing 0.26 wt % water, which is drier than *in situ* salt, which has approximately 0.5 to 1.0 wt % water. The height of the leveled salt was measured prior to compaction. After the initial lift was compacted by application of 3 MPE, the

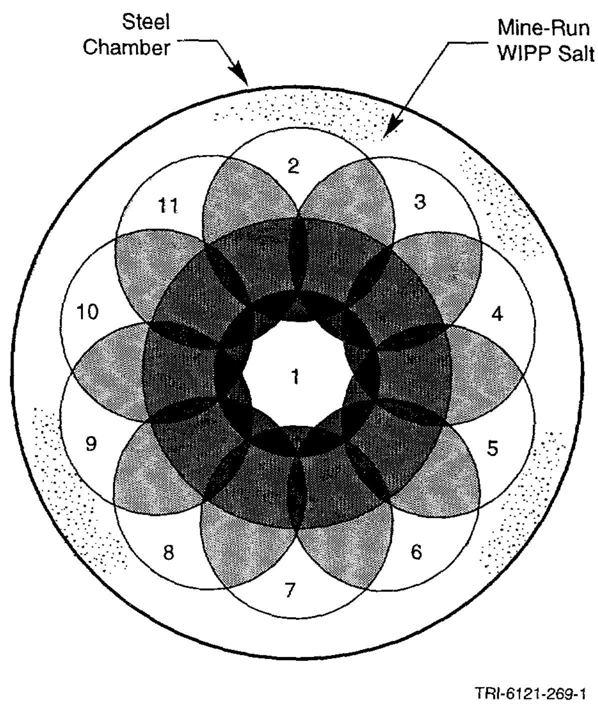

Figure 1. Compaction pattern.

salt was leveled and 57 height measurements were taken. Qualitatively, these geometric measurements revealed how much of the void volume had been eliminated. Because of the creation of approximately 15 cm of salt powder on top of the compacted salt, distortion of the chamber, and minor salt loss, the measurement of the void space eliminated was not exact. The first MPE eliminated more than half of the available void space; the second removed another 20 to 25%; and the third had little measurable effect. A second lift of mine-run salt, 0.6 m high, was placed in the chamber and compacted by applying 3 MPE. Powder on the top of the first lift was compacted to a high density as a consequence of compaction of the second lift. Subsequent geometric measurements suggested an overall fractional density of 87% for the compacted salt. Samples taken from the compacted mass and measured in the laboratory averaged 86%. In the vernacular of compaction descriptions, a unit called "fractional density" refers to the density of the compacted material relative to the density of intact Salado salt (2,160 kg/m^3). Fractional density is expressed either as percentage (e.g., 87%) or as a decimal (e.g., 0.87).

The second TDD test compacted salt with the addition of 1.0 wt % water. Application of 2 MPE resulted in compacted salt densities approaching 90% of that of intact rock salt. After each of the two dynamic compaction demonstrations, an unsuccessful attempt was made to drill cores directly from the compacted mass within the chamber. Excessive lateral movement at the bit face resulted in poor core recovery. Therefore, the chamber was opened and the compacted salt was cut into blocks that were shipped to RE/SPEC Inc., where cores were tested for gas permeability, density, and moisture content (Hansen et al., 1995).

These preliminary tests showed that dynamic compaction is a viable, simple, and practical method of compacting salt. The TDD preliminary results were the basis for undertaking the large-scale test described in this report.

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2.0 LSST DESCRIPTION

This section describes activities supporting large-scale dynamic compaction of mine-run WIPP salt and evaluation of the compacted salt. The success of the preliminary compaction demonstration warranted an effort to produce a data base of properties of compacted salt meeting SNL QA requirements. Because the WIPP seal system design will form part of the final compliance submittal and will be closely scrutinized by regulators and stakeholders, a formal compaction testing program implementing QA procedures was undertaken and completed. The LSST program involving dynamic compaction has a paper trail of objective evidence; hence, the results published from this study can be referenced as well as used for design and performance assessment. The field and laboratory testing was conducted within the framework of a reviewed and approved test plan (Hansen and Ahrens, 1995). Large-scale compaction was preceded by completion of several tasks and followed by a series of performance tests, all of which will be discussed in this section. The main endeavors discussed are as follows:

- Design and analyses of the chamber and tamper.
- Calculation of compaction energy.
- Compaction of sub-base soil.
- Compaction of mine-run WIPP salt.
- *In situ* gas permeability of the compacted salt mass.

2.1 Chamber and Tamper Design

Many factors were considered by the principal investigators (PIs) and the DOE program managers when the concepts for compaction demonstrations were first discussed. Logistics, time, budget, and safety concerns led to the consensus that an aboveground demonstration of dynamic compaction technology would best meet the program's immediate objectives. A setting more analogous to the placement of a shaft seal component might involve a vertical opening in the Salado. Such an underground test may be justifiable at some future time, but given the schedule for compliance activities and the lack of information on compaction of salt for design and PA, a decision was made to test the compaction concept above ground. Because the compaction demonstration was conducted above ground, it was necessary to fabricate a cylindrical chamber of significant proportions to simulate the shafts existing at the WIPP.

Design of the chamber and tamper followed SNL QA procedures for design and review. Obviously, design of a chamber to house salt for dynamic compaction is unique. The dynamic load could be calculated but distribution of the dynamic load over the steel structure was much more problematic. Designs were analyzed and modified by a registered, professional structural engineer. An SNL analyst calculated dynamic loading. A design review for the tamper, compaction chamber, and lifting assembly was conducted using an approved design review plan. An iterative process yielded the final design, which was then checked by an independent SNL structural design engineer. Records and drawings of this design review process were delivered to the Sandia WIPP Central File (SWCF), where they will remain as a permanent record. Schematics of the compaction chamber and the tamper are illustrated in Figures 2 and 3, respectively.

The resulting compaction chamber design has 2.5-in (63.5-mm) steel walls positioned within an equally thick ring which is welded to a baseplate. A welded connection between the compaction chamber and base was avoided to obviate stress concentrations at the base/chamber junction. Instead, twelve equally spaced holes were drilled through the ring and into the lower chamber wall. The bolt hole within the wall was threaded as detailed in Figure 2. Twelve steel bolts (38 mm in diameter) were inserted through the ring and screwed into the tank, attaching the base to the cylinder. This design concept was thought necessary to allow slight independent motion between the baseplate and the chamber, and thus avoid stress concentrations at that position.

The tamper consisted of 15 circular steel plates (10 cm thick and 124 cm in diameter) bolted together. Total weight was 9,144 kg. The demonstration concept was to keep the tamper connected by cable to the hoisting drum on the crane during the compaction test. A swivel and nylon sling were placed between the cable and tamper. While compaction was in progress, the sling and swivel were shielded from the tamper by car tires to prevent direct impact with the sides of the compaction vessel and the tamper.

2.2 Calculation of Compaction Energy

The compaction plan for this large-scale test differed from the TDD demonstration in that the tamper remained attached to the cable on the crane throughout the hoist and drop cycle. Compaction energy applied to the salt was based on highway construction experience (STS Consultants, 1986). Compaction was systematic and well controlled; however, compaction procedures were not optimized for this initial demonstration. A nominal initial compaction effort exceeding 3 MPE was applied to each of three lifts. One MPE equals 56,200 ft-lb/ft^3 [2.7 (10^6) joules/m^3] where the volume of interest is directly below the tamper. Three, 4-ft (1.2-m) lifts of salt were placed in the chamber and each lift was compacted with 3 MPE. As will be discussed later, the lower and middle lifts were actually compacted by greater than 3 MPE.

Based on results obtained during the TDD compaction tests, a decision was made to apply 3 MPE to the salt in the LSST compaction. The energy of each impact was accurately calculated from the known mass and velocity. The weight of the tamper and the tamper contact pressure were calculated according to a compaction construction handbook (STS Consultants, 1986). Crane height had a practical limit of about 50 ft. The terminal velocity of the cable-connected

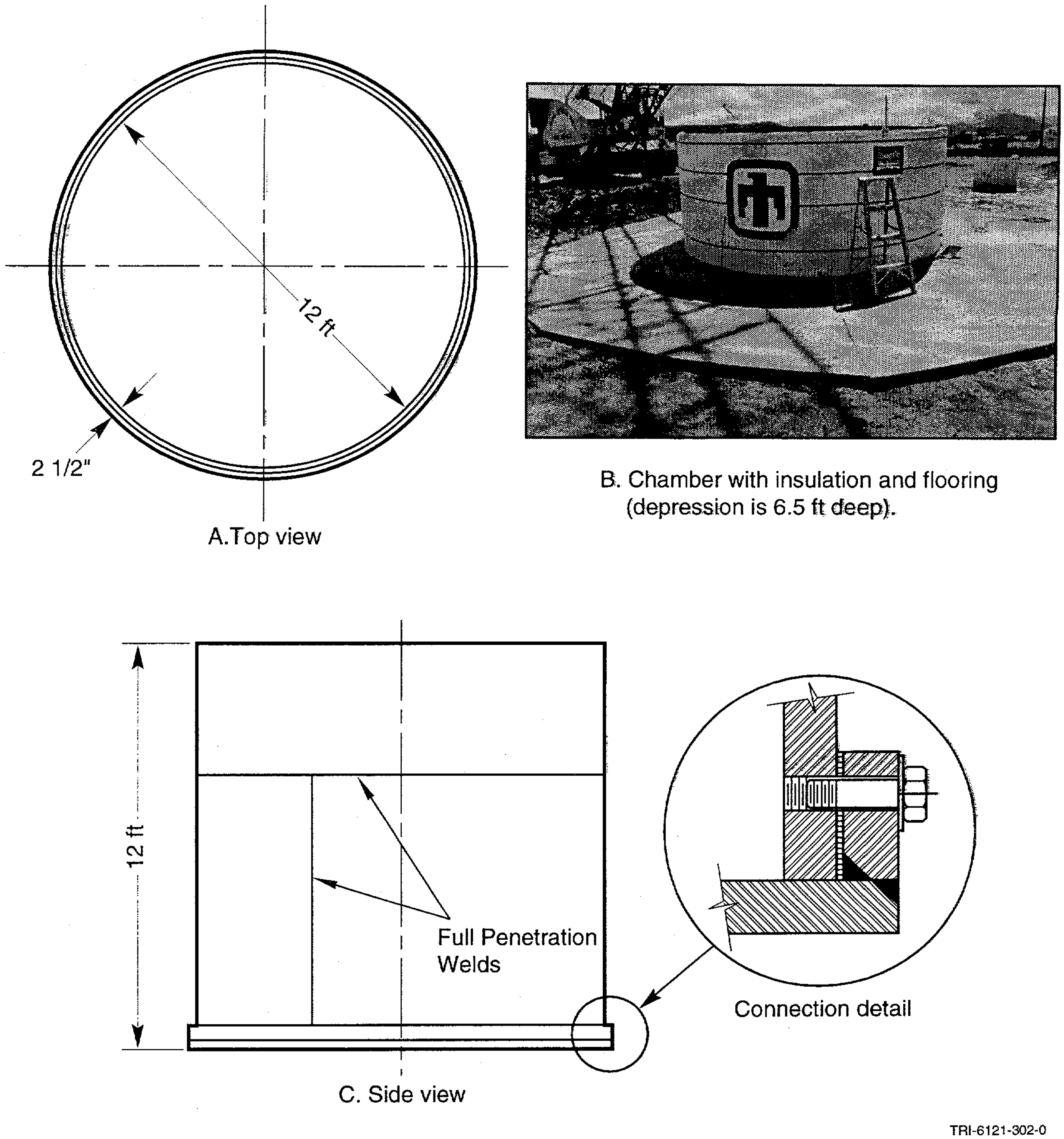

Figure 2. Compaction chamber.

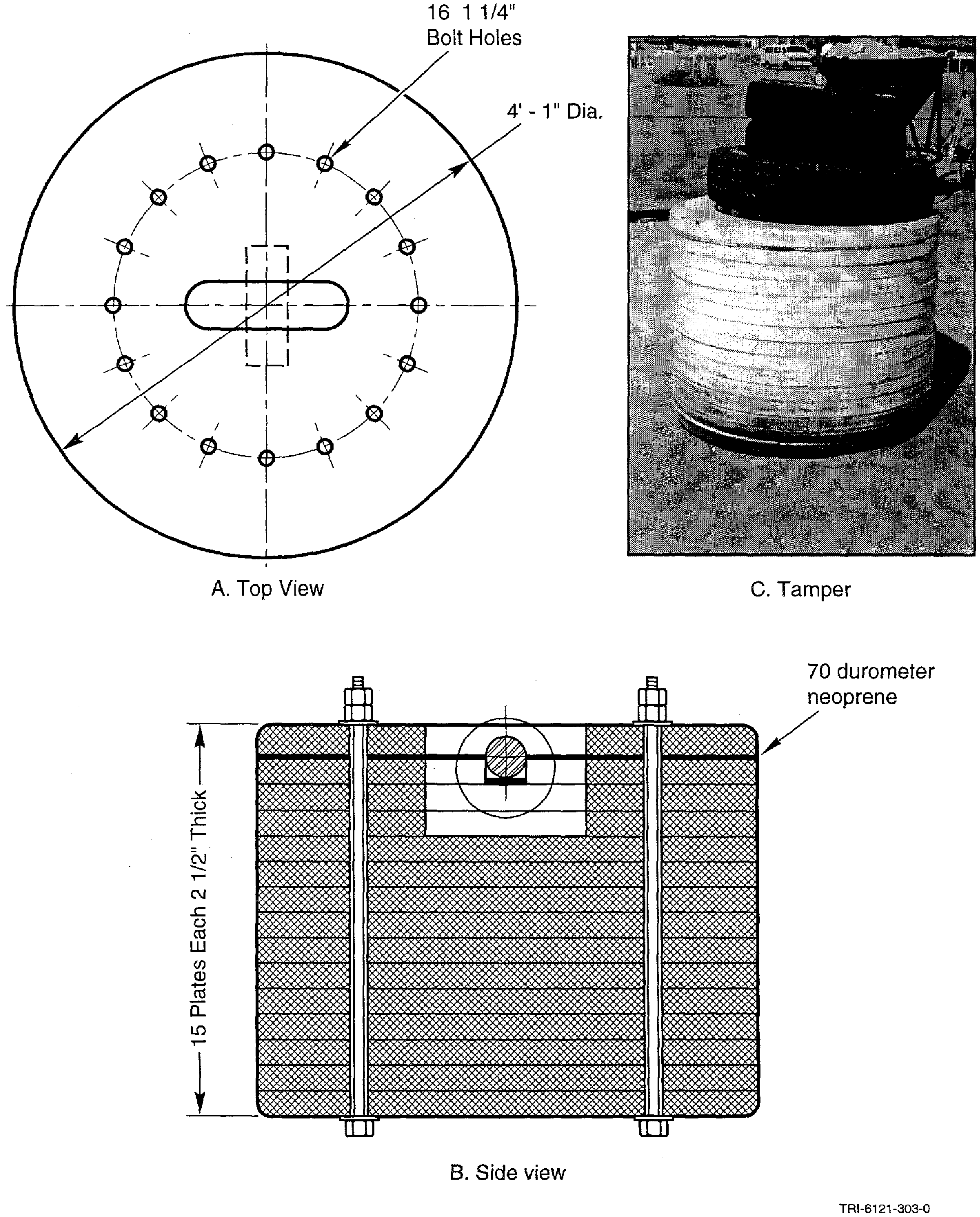

Figure 3. Tamper used for dynamic compaction demonstrations.

tamper was measured by SNL personnel utilizing specialized, high-speed video equipment for drop heights of 40 and 50 ft. An electronic timer integral with the camera was calibrated by the SNL Calibration Laboratory. The energy of one drop of the tamper from a height of 50 ft was calculated as follows:

$$E = \frac{1}{2} m v^2$$

where:

E	=	energy
m	=	mass (9,144.4 kg)
v	=	velocity (13.94 m/s @ 50 ft)
E	=	$\frac{1}{2}(9{,}144.4)\ \text{kg}\ (13.94\ \frac{\text{m}}{\text{s}})^2$
	=	$888{,}486\ \text{kg}\ \frac{\text{m}^2}{\text{s}^2}$ (joules)

Conversion units: 1 joule = 0.7376 ft-lb, E = 655,350 ft-lb

The number of drops required in each position to impart 1 MPE to the salt was determined by considering the volume of salt directly below the tamper in the initial lift thickness (52 ft^3). The number of drops to attain 1 MPE was 4.5, which was rounded up to 5, the next highest integer. Therefore, 15 drops were applied to each of the 11 drop positions to deliver at least 3 MPE. Testing required a total of 495 drops for the three lifts and a total energy transferred to the salt of 324,400,000 ft-lb.

2.3 Compaction of Soil

The LSST compaction demonstration was conducted in SNL Tech Area III near the foothills of the Sandia Mountains. The surface soils are predominantly sand mixed with clay. The Sandia Mountains and the valley containing the Rio Grande River are recent geologic structures. Pediment soils and sands derived from erosion of the Sandias were not expected to be consolidated. For this reason, the soil beneath the chamber was compacted before the chamber was situated for testing.

Soil was compacted within a circular area 6 m (20 ft) in diameter using the crane and tamper in a fashion to be used later for compaction of salt. In addition, an "ironing" plate was used to smooth the impact surface. Soil compaction was completed from December 10 to 23, 1994. In a general sense, the soil was compacted with as much energy as the salt would eventually be compacted. The soil would not subsequently experience equivalent forces because a layer (lift) of salt and the steel baseplate of the compaction chamber would lie between the tamper and the compacted ground surface. Soil compaction was considered sufficient when the tamper, dropped from 15.2 m (50 ft), penetrated less than 5 cm (2 in). The original ground surface was lowered approximately 2 m (6.5 ft) by compaction.

2.4 Compaction Procedure

There were several prerequisites before compaction of salt began. This section discusses some preliminary arrangements and test controls. The "mine-run" salt is described. Moisture adjustment, a first-order test parameter, and the chamber loading technique are presented in this section. The tamping sequence, or drop pattern, was modified slightly as compaction progressed. Finally, this LSST activity occurred during blustery and uncertain winter weather. Environmental controls to protect the test chamber and its contents were used. These prerequisite activities and contingency measures were important to the success of the compaction demonstration.

2.4.1 Moisture Adjustment

"Mine-run" salt was trucked from the WIPP site. Only water was added to the mine-run salt, although some larger chunks were hand picked from the pile before the chamber was loaded. The salt was stored in a large, specially fabricated tent as preparations were made for placing it in the chamber. Before testing began, salt from the storage pile was sampled for moisture content. The volume of water necessary to achieve 1.0 wt % water was calculated. Water was added uniformly using an airless paint sprayer as the salt was discharged from a conveyor into a loading bucket. Samples were taken from the chamber periodically as each lift was loaded. Starting (natural) moisture content and the "as-loaded" moisture content measured for the salt on the three lifts are summarized in Table 1.

Table 1. Moisture Content of Compacted Salt

Lift No.	Original Moisture (wt %)	As-Loaded (wt %)
1	0.22	1.00
2	0.18	1.00
3	0.15	0.90

2.4.2 Loading the Chamber

Figure 4 is a photograph of the operations near the SNL Tech Area III Drop Tower Facility. All test activities were conducted under the drop tower standard operating procedures as specified in the governing test plan (Hansen and Ahrens, 1995). Salt was placed in

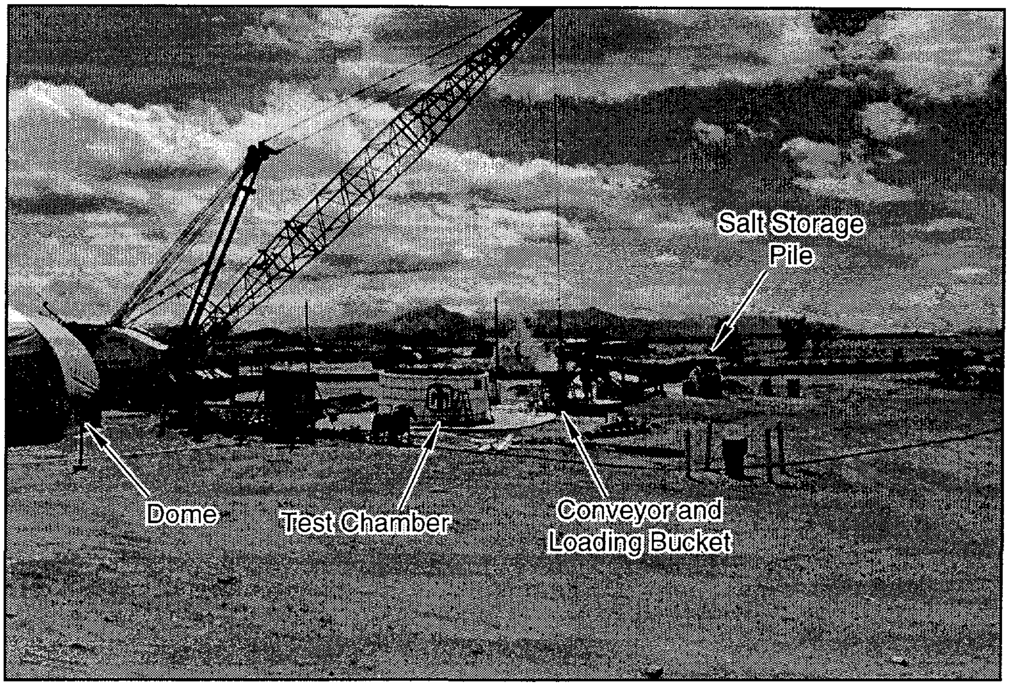

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Figure 4. Panorama of Tech Area III dynamic compaction test.

the compaction chamber using a 1-cubic yard capacity concrete bucket. A belt conveyor was positioned to load from the salt storage tent and discharge into the concrete bucket, which was attached to the crane cable. At first, the conveyor was charged by hand shoveling salt from the pile. Later the conveyor was loaded using a small, front-end loader. As the salt was discharged from the conveyor belt, a fine water mist was sprayed onto it. With practice, the precalibrated amount of water was used up as the last of the salt cascaded into the bucket. If a small volume of water remained in the reservoir, it was sprayed into the compaction chamber. The bucket was transported to the chamber using the crane that was on site to hoist and drop the compaction tamper. Each lift was 1.2 m (4 ft) in original thickness. After the salt was placed in the chamber, it was manually leveled so that the surface did not vary more than 5 cm.

2.4.3 Drop Procedure

As detailed in Section 2.2, one MPE required approximately 4.5 drops; therefore 5 drops were made in each position. The total number of drops required for the application of 3 MPE to three lifts was calculated to be 495 (11 x 3 x 5 x 3), where:

Number of drop positions: 11

Number of salt lifts: 3

Number of drops/MPE: 5

Number of MPE: 3

There were 11 drop positions for salt compaction (Figure 1). Normally when maximum dynamic compaction is desired, such as in highway construction, the tamper is dropped until the impact crater ceases to deepen. Such a measurement in this test was deemed impractical for schedule and safety reasons. Overlap of impact areas coupled with estimates of impact energy ensured that the salt was compacted more than 3 MPE.

The following depth of compaction formula is from STS Consultants (1986):

$$D_m = n\sqrt{T_m \cdot H_m}$$

where:

D_m = compaction depth in meters
n = variable factor
T_m = tamper mass in metric tons
H_m = drop height in meters

No information was available regarding the value of *n* for salt. STS Consultants noted that dynamic compaction is most effective on sand ($n = 0.77$) and least effective on cohesive clay ($n = 0.46$). Mine-run salt is noncohesive and visually more like sand than clay. Thus, $n = 0.5$ was selected and thought to be conservative. For this test configuration:

$$D_m = 0.5\sqrt{9.2 \cdot 15.2} = 5.9\,\text{m (or 19.4 ft)}$$

These calculations suggest that the influence of the tamper extended well below the base of the compaction chamber. Qualitative observations discussed in subsequent sections affirm these calculations. Depth of compactive influence may be a concern during placement of salt in the shafts.

2.4.4 Test Environment Concerns

Compaction demonstrations were conducted on the open piedmont during the winter. Protection of facilities and creation of a reasonable ambient temperature were considered good practice. This section discusses measures implemented for these purposes. Protection of the salt both in the chamber and in the storage pile during inclement weather was achieved as follows:

Dome: A commercially available dome constructed of polypropylene and aluminum (15 ft high at the center, 30 ft in diameter at the base, and a weight of 1,257 lb) protected the compaction chamber. The dome was removed for loading and compacting and replaced during nonoperational periods. It was equipped with a skylight and an entrance door (see Figure 5).

Tarp: A custom, polyethylene-impregnated cloth tarpaulin, supported by steel staves, was used to protect the compaction chamber during periods of rain or snow.

Salt Tent: A polyethylene tent was fabricated to house the storage pile of salt. A frame was anchored to the ground and a tarpaulin draped over the supports. A zippered door with storm flap provided human access. When loading operations were under way, the tarp was pulled back from the frame, revealing the salt pile.

Beyond mere protection of the salt and the compaction chamber, an attempt was made to keep the salt at a relatively uniform temperature of 80°F, which is similar to temperatures anticipated deep in the shafts at the WIPP site. More important than simulating its potential placement environment, heating kept the salt from experiencing widely fluctuating temperatures and freezing. Laboratory experiments conducted at the University of Nevada at Reno indicated a decrease in compactive efficiency as temperature decreases. Simulation of temperature in the WIPP shafts was desirable to obtain meaningful results. Temperature control consisted of several elements as described in the following paragraphs.

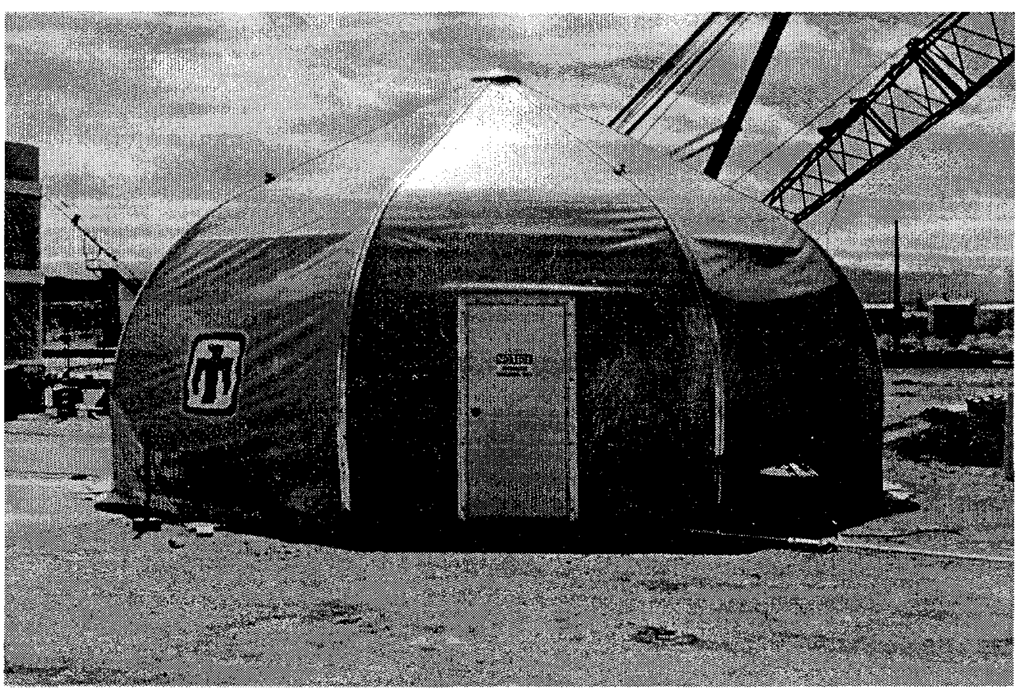

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Figure 5. Test dome.

Blanket Heaters: Silicone rubber blanket heaters (144 in long, 23 in wide and 0.125 in thick) were fastened to the exterior of the compaction chamber in three horizontal bands consisting of four heaters each. The bottom of the lowest band was located approximately 8 in above the bottom of the baseplate and the heater bands were separated by 2-ft gaps. Individual heaters were connected with springs which supplied sufficient tension to keep the heaters in place on the chamber.

The blanket heaters, which operated at 277 volts, were rated at 1 watt/in^2 and designed to overcome a temperature difference of 40°F in 16 hours. The manufacturer stated that the heaters could not self-destruct even if left on indefinitely at full power. The heaters were wired in parallel, with each pair operated by two legs of the 480-volt power. One temperature probe was situated against the exterior of the steel chamber under the center of one heater of each pair. The six temperature probes were wired to an IBM personal computer (PC), located in Building 6516 of Tech Area III approximately 70 ft from the compaction chamber. Two temperature control cards were inserted in the computer, which controlled all the heaters. The heaters were insulated with expanded polystyrene before the chamber was placed in the compacted soil depression.

Space Heaters: Wheel-mounted space heaters (480 volts, 15,000 Btu) were used under the dome and under the salt storage tent. Two were situated 180 degrees apart in the dome and directed horizontally, creating a rotational flow of heated air. A computer control averaged two temperature probes also situated 180 degrees apart near the top of the compaction chamber as feedback to maintain 85 ± 5°F. These heaters were equipped with powerful fans and worked well. Each had an internal, thermostatic control which was marked low, high, and full on. When activated by the computer sensor feedback, the heaters were operated in the full-on mode. A single heater was situated inside the salt storage tent and directed horizontally. A temperature probe controlling this heater was buried approximately 0.15 m (6 in) below the salt surface. This heater was also computer controlled at 85 ± 5°F, but ran almost continuously because the temperature of the salt storage pile seldom reached the control setting.

Electrical power: Power was supplied by a 480-volt generator situated approximately 250 ft from the compaction chamber. The generator was always shut off prior to anyone working within 25 ft of the chamber.

Platform: Because the chamber rested in a depression, a platform was constructed between the original surface and the side of the compaction chamber. Nineteen 6-in angle-iron brackets were equally spaced and welded on the exterior circumference of the chamber approximately 6 ft above its base. One 2-in x 6-in pine plank, 10 ft long was bolted to each bracket and positioned radially from the chamber. The planks were covered with 3/4-in-thick plywood, forming a working floor which completely covered the compaction depression. The platform is shown in the photograph in Figure 2.

3.0 NARRATIVE OF COMPACTION ACTIVITIES

This section chronicles events in the field. Section 3.1 describes "normal" operations and Section 3.2 describes "unusual" events. A more detailed narrative from daily logs is given in Appendix A. Complete records are inventoried in the SWCF Library.

3.1 General Operations

Routine operations were conducted between 8:00 a.m. and 4:00 p.m. weekdays (and two Saturdays). Work began on 12/14/94 and was concluded on 5/17/95. The standard crew conducting daily activities consisted of the following personnel: the PI, the drop tower director, two laborers, a crane operator, and a crane helper (rigger). In addition, many other personnel worked within Tech Area III on an as-needed basis for short periods. They were involved inspections, electrical power connections, computer programming, carpentering, welding, calibrating, and many other services. After compaction was complete, a drill crew and gas flow specialists made *in situ* permeability measurements. All activities were conducted under standard operating procedure (SOP) SP472185, as modified by the inclusion of six technical operating procedures (TOPs). Organization 2761 was responsible for all environmental safety and health (ES&H) during the test.

Building 6516, a one-story metal structure approximately 30 ft x 20 ft located approximately 70 ft from the compaction chamber, was used as a control center during the test. This building provided some relief from the cold temperatures encountered during the work and was used to store equipment. The building has electrical power, telephone, radio, anemometer readout, storage cabinets, desks, and chairs. The IBM 486-50 computer used for heater control was situated in this structure.

Each day's activities began with a safety meeting. The work for that day was outlined and discussed with special emphasis on safety. One notable safety inspection occurred every day on the crane boom. When the crane released the tamper, it was subjected to a significant recoil, which conceivably could cause structural damage to the boom. Therefore, each morning, the boom was lowered and carefully inspected. Release of the tamper resulted in high rotational speed of the sheave wheel. This wheel was lubricated each morning as recommended by the SNL crane inspectors. The hoisting sling, cable, and swivel were checked daily for damage and replaced as required.

Subfreezing temperatures (mostly at night), rain, snow, and high winds were encountered during the test. The computer-controlled heating system worked well and appeared to warm the salt sufficiently to avoid any significant effects of temperature. Rain and snow caused minor delays (the salt was always protected by waterproof covers during such periods). The tamper was successfully dropped in winds gusting to 30 mph. The mass of the tamper created enough inertia to provide stability. The dome was successfully moved in gusty winds, as well.

With the exception of two notable problems discussed in the following section, all operations went reasonably well. An abridged daily chronology of events is given in Appendix A.

3.2 Unusual Events

Two significant problems occurred while tamping operations were under way. Early in the compaction testing, bolts connecting the lower plate and the upper chamber sheared. Near the end of testing, the lowest blanket heater was damaged. Neither event compromised the data quality objectives of the compaction demonstration. However, these events are noteworthy and are explained in more detail in this section.

3.2.1 Broken Bolts

The initial drop sequence was executed in a manner similar to that used in the TDD (Figure 1), except that the tamper was dropped in every other position, rather than advancing sequentially. This allowed the tamper to avoid most of the impact crater of the preceding drop position. Progression through the drop pattern in a clockwise manner caused a clockwise rotation of the chamber, which in turn rotated the wood floor because it was bolted to the chamber. It was the rotation of the wood flooring that first gave rise to concern. A vertical, electrical conduit carrying power to the dome space heater plugs passed through a rectangular hole in the floor. Rotation of the floor bent the conduit and there was concern that electrical wires below the floor were of insufficient length to accommodate additional rotation. Therefore, after 45 drops, a portion of the floor was removed to allow electricians to lengthen the wiring and reposition the conduit.

At this time, it was noticed that two of the bolts securing the baseplate to the chamber were broken. This discovery led to a closer examination revealing that all twelve bolts had been broken by the first 45 blows from the tamper. It is possible that the compaction demonstration could have been completed without the baseplate and the vessel being attached, but a bracket system was developed to attach the baseplate to the chamber to ensure integrity of the system. Design and installation of the bracket system resulted in a 2-week delay in compaction. The brackets were designed and analyzed by the same team that designed the original chamber and vessel. During installation, it was noticed that bolt holes did not align on one side of the chamber, apparently because compaction forced salt between the upper chamber and the baseplate. The demonstration probably could have proceeded without connecting the baseplate and chamber, but to ensure all technical and safety issues were addressed, a decision was made to attach the upper chamber to the baseplate.

A tiedown assembly consisting of an upper bracket welded to the cylinder, a lower bracket welded to the baseplate ring, and high-strength threaded connecting rods was developed. These were fabricated in Albuquerque and welded to the chamber at the test site. Installation of the brackets required the removal of the lower band of blanket heaters. When the brackets were attached, the lower band of blanket heaters was reinstalled, but the brackets forced the upper 15 cm of the heaters to be folded. Polystyrene insulation was placed in the fold to prevent the heaters from contacting themselves. All other insulation was removed. The attachment of the tie-down assembly caused an ensuing problem with the lower heater.

3.2.2 Damaged Blanket Heaters

Near the end of compaction of the third lift, soot was noted in the dome and the computer indicated that all temperature probes were disconnected. A portion of the floor was taken up to reveal damage to the lower blanket heater. Polystyrene in the folded portion of the lower heater band had melted. Evidently enough heat had been generated on the top of some of the base brackets to melt portions of the blanket heaters. Insulation was melted on some wiring.

Because compaction was nearly finished and the weather had warmed, the insulation and lower heater band were removed. Damaged wiring was also removed and the remaining blanket heaters rewired. At this time, it was discovered that a card in the computer had (coincidentally) failed. The solid-state relays were then hard wired to permit manual operation of the blanket heaters, but this mode of operation elevated the temperature too high, too fast. Thereafter, the chamber was heated with the space heaters while it was covered with the dome. Heating with the space heaters during nontest hours maintained the salt temperature reasonably well for the few remaining days of compaction.

3.3 Other Operational Notes

Techniques were improved and modified during the testing as events occurred and knowledge was gained. Because such experiments may again be attempted, a few of these insights are worth recording here. As noted above, clockwise compaction resulted in rotation of the entire compacting chamber. The first consequence of the rotation was the fortuitous discovery of the broken bolts. After repair had been made to tie the baseplate and upper chamber together, an alternative tamping sequence was used. Tamping proceeded clockwise using every other drop position. The salt was then leveled and the skipped positions were compacted in a counterclockwise manner. This eliminated rotation of the chamber.

Questions pertaining to safety were answered by the drop tower director. Decisions concerning testing and evaluation were made by either of the two PIs. As noted in the test plan, several anticipated impactive events occurred, but because of advance preparation or good fortune, no severe problems arose. The anticipated and other minor unanticipated events are listed here with the resolution and/or consequence.

Excessive wind: Wind speeds of less than 30 mph had little effect on field testing activities. Compaction drops were made successfully in 30-mph winds.

Inclement weather: Measures taken to warm the compaction chamber and salt succeeded. Salt was shielded from rain and snow by covering the chamber with the dome at night or a tarpaulin for short periods during the day. Salt in the salt storage tent was covered except for short periods when the chamber was being loaded or salt was being received from the WIPP.

Destruction of floor supports: The floor support planks were bolted to steel angles welded to the chamber. Originally, plank ends at the chamber were left square. When the chamber rotated, the outer end of the planks lagged behind. As a result, 14 of the floor supports were split. The floor was removed and new supports prepared with the ends rounded at the chamber. In addition, a cable tied all 19 planks together near their outer end and there were two, triangular (in plan) cables tied to the tank, located 180 degrees apart. This arrangement permitted the floor to rotate without damage.

Inclination of the compaction chamber: The entire chamber tended to tilt as tamping continued. At the end of the test, the inclination was about 5 degrees toward the WNW. Apparently, soil on the WNW side had less bearing capacity than the soil on the ESE side. The possibility of soil compaction was anticipated and extensive precompaction was completed. Continued soil compaction during salt compaction was surprising and we are fortunate it was limited. If another test is conducted, the tank might be removed and additional precompaction of the soil undertaken.

Minimal core recovery: As discussed in later sections, drill core from the compacted salt was almost completely broken. The inability to recover drill core from the compacted salt was anticipated and not considered critical. Three blocks of compacted salt were obtained from the lowest lift for laboratory testing (to be discussed in a subsequent report). The blocks were approximately 0.1 m^3. The top half of each block contained compacted powder which had formed on the top of Lift 1.

4.0 RESULTS

Many of the results from this experiment were presented in the previous sections because this is a report on a unique compaction demonstration. Procedural detail, operational decisions, problems and problem solving have all been presented so far. In this section we will describe some qualitative results, discuss *in situ* permeability testing, and summarize demobilization.

4.1 The Compacted Mass

The initial drop on uncompacted salt resulted in approximately 0.5 m of tamper penetration. The crushed salt was compacted vertically and displaced laterally, forming an impact crater. The rim of the crater bulged upward approximately 5-10 cm. Succeeding drops penetrated progressively less as the salt was compacted. After compaction, the surface of each lift was covered with approximately 0.4 m of powdered salt. The powder was underlain by compacted salt whose cohesiveness and density apparently increased with depth. Compaction of each subsequent lift compacted the powder of the preceding lift into a dense, indurated mass. Visually, the densest and most cohesive material was located in Lift 1. The average compacted density was approximately 0.9 of the density of intact Salado salt. In addition, salt strongly adhered to all interior surfaces of the compaction chamber.

A minor amount (perhaps as much as a kilogram) of salt "splashed" out of the chamber during compaction of the third lift. This loss was of no consequence to the test.

When permeability testing was finished and the salt was removed from the chamber, density appeared to increase with depth and salt adhered to the interior of the chamber. This result verifies the theoretical shape of the compaction achieved by this method. The compactive influence expands outward from the base of the tamper and downward. This results in the salt being strongly compacted against the walls of the chamber as it would be against the more compatible salt that forms the walls in the WIPP shafts. In addition, the depth of compaction clearly indicates that the lowest lift (Lift 1) was further compacted during compaction of the second and third lifts. This multiple compaction effect would advance up the shaft as salt is compacted in successive lifts.

4.2 *In Situ* Gas Permeability

As described in the test plan, the procedure for testing gas permeability has been used extensively in the WIPP underground. The *in situ* testing was conducted by INTERA personnel with considerable experience. Here we describe the equipment, operations, and application to *in* *situ* testing of the compacted mass. Final results of field tests will be given with laboratory measurements of densities, water content, and permeabilities in an upcoming report.

4.2.1 Equipment

The design and conduct of gas flow testing are based on successful densification of the salt by dynamic compaction. *In situ* testing of the compacted salt followed procedure SOP 447 and utilized tools developed and implemented at the WIPP over the past several years (e.g., Stormont et al., 1991). Equipment and techniques have been documented in reviewed WIPP procedures on file in the SNL Records Center.

Tool: A 10-ft-long, four-packer tool was used to conduct gas flow measurements in the boreholes. These tests were guarded (to detect leaks) through the use of packer isolated guard zones on either side of the test interval. The guard zones contained very sensitive transducers which detected a pressure increase if gas leaked past the packers.

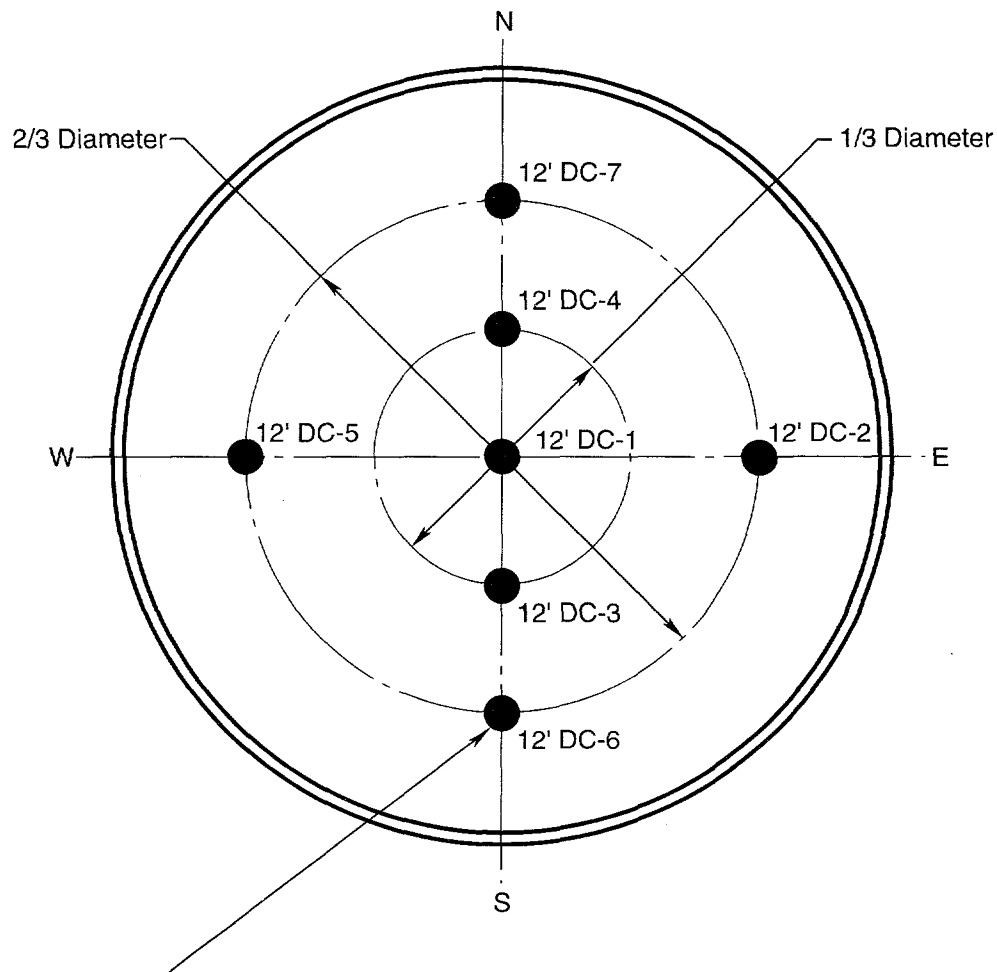
Pressure Transducers: Pressure transducers used during this test employed a strain-gauged diaphragm in which an applied pressure correlates with change in the electrical balance of a Wheatstone bridge. Test interval pressures were 20 psig above ambient.

Fluid Flow Control Panel and Manifold: The fluid flow control manifold used in previous WIPP experiments was designed and developed specifically for testing gas flow in low-permeability formations. Its use is governed by SNL SOP 447.

Electronic Data Acquisition System for In Situ Testing: The electronic data acquisition system associated with gas flow testing consisted of a data control unit which transferred data to a magnetic disk. The resolution of this system was consistent with the requirements of the data quality objectives and the gauges to be scanned, as discussed in the test plan.

4.2.2 Test Hole Coring

In situ gas permeability testing was conducted immediately after compaction. Seven, 4-in diameter diamond drill holes were sequentially drilled, tested for permeability, and then sealed by completely filling them with an expansive, quick-setting cement to prevent communication with a new test hole. A plan view of the drillholes is shown in Figure 6. All holes were drilled parallel to the walls of the chamber. The second hole was drilled to the steel bottom of the chamber and the other six were terminated above the steel base. Some of the broken core was photographed but none was saved. One core of sufficient intact length for laboratory testing was sealed and handled according to WIPP core handling procedure [quality assurance procedure (QAP) 17-2]. This core was sent to RE/SPEC, Inc., with appropriate chain of custody documentation, for further testing.



Notes:
Test holes are depicted with ● and drilled with a 10-cm diameter bit.
DC refers to dynamic compaction; 6 refers to hole sequence number.
Hole 12' DC-2 drilled to steel base, remaining holes drilled 15-cm short of base.

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Figure 6. Field test core hole pattern.

Although the drill mount was solid, the eccentricity of the barrel and shaft made it impossible to eliminate lateral motion at the face bit. This resulted in the initial third of the hole being too rough to permit packer seating. Therefore, only Lifts 1 and 2 were tested in each hole. Two intervals were tested in each of seven drill holes (Figure 6) and all revealed very consistent gas flow permeabilities. There are plans to publish a technical summary of *in situ* gas flow testing and laboratory results at a later date.

4.2.3 *In Situ* Permeability Testing

The gas-injection tests conducted to evaluate *in situ* permeability of the compacted mass have been described in the test plan. This type of testing has also been used extensively in the WIPP underground (Torres et al., 1992; Pickens et al., 1995). This section briefly describes the test procedure, data analysis, and results.

Testing was accomplished by placing the four-packer tool in a freshly drilled borehole and inflating packers one and two to a pressure of 50 psig ± 5 psig. Packers were placed so that packer 1 spanned the interface between Lift 1 and Lift 2. After a 30-minute packer compliance period was completed, the data acquisition system was activated and verifications of packer set pressure, reservoir pressure, and regulator set pressure (20 psig ± 2 psig) were performed. Upon completion of pressure verifications, test and guard zones were vented and then shut in to the transducers. Flow was started into the test zone interval and continued until a reservoir pressure of 275 psig ± 25 psig was observed. Flow was then stopped to the interval and decay of test zone pressure was observed until it had fallen to ambient pressure and for a period beyond ambient so that each complete gas flow test lasted at least 30 minutes.

The decay of gas pressure in the test zone is a function of the flow rate into the test zone and of the material tested. The ability of the compacted mass to dissipate the gas is a function of several properties, including the permeability of the material to gas. Observation of the test zone behavior during conduct of the test enables the field test engineer to derive rough estimates of the material's permeability. Quantitative values of the permeability of the compacted mass were developed by a computer-aided analysis tool known as GTFM (graph theoretical field model). The theoretical basis and procedures associated with the GTFM are described in some detail in Beauheim et al. (1993).

Data collected during the tests were entered into a commercial spreadsheet to perform the calculations necessary to output the elapsed test time in seconds, test zone pressure in pascals, cumulative gas flow in cubic meters at standard temperature and pressure, and change in test zone pressure from the beginning of the pressure decay cycle. These data were input into the GTFM to find optimized estimates of gas permeability and the flow dimension index. The index provides an estimate of the flow path of the injected fluid. An index of 2.0 indicates that the flow follows a radial path from the cylindrical borehole. When the index is greater than 2.0, both radial and axial flow are likely. Values of the formation thickness were assumed to be equivalent to the test zone length; porosity was assumed to be 7%; and the value of the dynamic viscosity for the nitrogen gas was obtained from tables in the *CRC Handbook of Chemistry and* Physics (CRC, 1994/1995).

In all, seven boreholes were drilled and each was tested at two depths. The tests proceeded smoothly and quickly. From the table of results (Table 2), it seems apparent that the mass is very uniform with respect to gas permeability. It should be pointed out that higher values have been observed in gas flow testing of disturbed native formations at WIPP. The flow dimensions fit by GTFM (all were >2.0) indicate that the flow did not move just radially through the mass, but had a significant vertical component as well. Table 2 is composed of preliminary data only. The test identifiers follow a protocol of three-letter test series designation, two-digit borehole number, and 1.1 or 1.2, depending upon the lift tested.

Table 2. Preliminary Permeability Values of Compacted Salt Mass

Test Number	Date Tested	Estimated k_{gas}	Flow Dimension
DCT01L1	04/06/95	1.31E-13 m^2	2.32
DCT01L2	04/06/95	1.06E-13 m^2	2.74
DCT02L1	04/07/95	8.91E-14 m^2	2.44
DCT02L2	04/10/95	1.34E-13 m^2	2.73
DCT03L1	04/11/95	4.03E-14 m^2	2.79
DCT03L2	04/11/95	5.45E-14 m^2	3.01
DCT04L1	04/11/95	7.38E-14 m^2	2.54
DCT04L2	04/11/95	5.24E-14 m^2	3.17
DCT05L1	04/12/95	1.34E-13 m^2	2.22
DCT05L2	04/12/95	1.19E-13 m^2	2.78
DCT06L1	04/12/95	8.14E-14 m^2	2.53
DCT06L2	04/12/95	1.11E-13 m^2	2.83
DCT07L1	04/13/95	8.61E-14 m^2	2.61
DCT07L2	04/13/95	3.98E-14 m^2	3.51
AVERAGE	ALL TESTS	8.95E-14 m^2	

4.3 Preliminary Laboratory Results

To date, limited information has been obtained from laboratory testing of cores. Testing is under way and there are plans to include results in a future report, along with complete analyses of *in situ* permeability. This section contains the values of water content from each lift and preliminary density and permeability measured on one sample.

Although coring broke the compacted salt into untestable pieces, water content could be readily determined from the remnants. Table 3 summarizes four measurements. A calibrated amount of water to produce a total equaling 1.0 wt % was added to the crushed salt as it was loaded into the chamber. It is apparent that some water had been lost by the time the test was terminated. It is likely that maintenance of a constant temperature of 80°F drove off some of the water.

One sample (identified as DC-5-3/1) having sufficient length for permeability testing was recovered during coring of *in situ* permeability test holes. Its fractional density of 0.899 was determined from the data given in Table 4. Visually most of the compacted mass was of comparable density. Additional density data will be included in a forthcoming laboratory report.

Sample DC-5-3/1 was tested for nitrogen permeability. In the laboratory a small confining pressure (1 MPa) was applied to prevent gas from passing between the jacket and the rock specimen. The initial permeability of 5E-14 m^2 agreed well with *in situ* measurements.

4.4 Demobilization

Salt is a nonregulated industrial waste but permission to dispose of the test material in the Albuquerque landfill dump was denied. It had to be removed mechanically from the chamber. The salt was strongly and uniformly compacted within the chamber and adhered tightly to the chamber sides. Its removal required considerable effort. The density and cohesiveness of the salt increased with depth and the salt stuck strongly to all interior surfaces of the chamber. A tracked excavator removed the upper half of the salt and its bucket facilitated the manual removal of salt to a depth of 3 m below the rim (the approximate top of Lift 1). Removal of the first lift necessitated the use of a jackhammer as well as shovels and picks.

A chain saw equipped with tungsten carbide chains was used to extract three large samples (0.1 m^3). These were taken from the center of the NW, NE, and SE quadrants and the top of each cube consisted of compacted powder. These were sealed and shipped to RE/SPEC Inc. where they will be cored and tested for density, gas permeability, and moisture content. Final removal of salt required the use of a grinder equipped with a coarse wire wheel and a vacuum. The salt was placed on the ground near the chamber until it was returned to the surface spoil pile at the WIPP site.

Table 3. Summary of Moisture Content for
Dynamically Compacted, Crushed WIPP Salt Specimens

Specimen	Moisture Content (%)
12' DC - 1 - 3 Specimen 1	0.534
12' DC - 1 - 3 Specimen 2	0.497
12' DC - 1 - 3 Specimen 3	1.03
12' DC - 1 - 3 Specimen 4	0.692

Table 4. Density Data for Specimen 12' DC - 5 - 3/1

Length (m)	0.20496
Diameter (m)	0.093035
Mass (kg)	2.70440
Density (kg/m^3)	1940.97
Fractional density	0.899[a]

[a] Based on an intact density value of 2,160 kg/m^3.

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5.0 CONCLUDING REMARKS

Measurements taken during *in situ* flow tests are the first of their kind, providing valuable information for the WIPP project. Values of permeability will be used for seal design and evaluation as well as for PA computations. Because compacted salt is expected to seal the repository for 10,000 years, its range of initial properties is very important. PA activities require the use of conceptual models for the repository which, in general, do not require exact values of permeabilities. Instead, ranges of these properties are input to PA calculations through probabilistic analysis. Permeability values often range over several orders of magnitude. Since the conceptual models used for seal design and PA are inherently coarse and involve other wide uncertainties, derivation of permeabilities within an order of magnitude falls within the range of uncertainty of the model. As can be seen from preliminary results, the compaction demonstrations have greatly reduced the uncertainty regarding achievable initial permeability of the compacted crushed salt.

Most of this text documents successful dynamic compaction of mine-run salt using technology that could be suitable for placing seal components in the WIPP shafts. Densities approaching 90% of intact salt were achieved within the compacted mass. This constitutes fundamental design information. Previous design assumptions based on laboratory tests suggested fairly low initial densities for placement. Lab and intermediate-scale tests really did not address large-scale seal applications. Permeabilities achieved in this experiment were of the order of 9E-14 m^2, and uniform throughout. Previous lab studies suggested lower permeabilities at a fractional density of 0.9, so these large-scale tests provide important information with respect to expectations of compacted salt seal components in the early years after placement.

A few key questions remain. It is certain that this compaction demonstration is only a first step toward understanding large-scale dynamic compaction of salt. Work reported here is a demonstration, not an optimization. Some statements can be made with respect to placement conditions likely to increase density and lower permeability. Based on the observation from this demonstration that powdered salt is thoroughly indurated by compaction, it is very probable that *in situ* permeability could be lowered if salt were pulverized prior to compaction. In addition, a slightly higher moisture content would probably result in increased density of dynamically compacted salt. The additional water would be adsorbed on a greatly increased surface area created by crushing mine-run salt. Although the microprocesses governing time-dependent densification have not yet been extensively documented, evidence to date suggests that solution and reprecipitation play a key role (Brodsky et al., 1995). Additional water also appears to enhance dislocation mobility. With minor, easily implemented changes, the initial as-placed characteristics of compacted salt can reasonably be expected to be very favorable relative to performance specifications. Pulverization and addition of 2 wt % water may be suitable parameter changes if another compaction demonstration is attempted.

Dynamic compaction appears to be an efficient and practical construction technology that could be adapted for compacting hundreds of vertical feet of salt in each of the four shafts at the WIPP. Design of viable concepts remains to be undertaken, but a Polar crane utilizing stored hydraulic energy appears feasible. A larger, heavier tamper may be used in constructing shaft seal components and depth of compaction would be increased over that of this demonstration. With certain changes to the construction method from those used in this demonstration, such as crushed salt gradation and moisture, compaction of salt in the shaft could easily exceed densities and reduce permeabilities from those measured here.

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APPENDIX A: CHRONOLOGY OF EVENTS

E.H. Ahrens kept a project log included here. The original log is part of the records package to be submitted to the SWCF. Temperatures were noted during each compaction sequence and were usually taken near the open door of Building 6516 with a hand-held temperature/hygrometer unit calibrated by the SNL Calibration Laboratory.

Start	End	Activities
12/10/94	12/23/94	Compacted soil to serve as a drop base. Determined the terminal velocity of the tamper when attached to the crane and dropped 40' and 50'.
1/23/95	1/23/95	Welded blanket heater probes on chamber and began construction of the 480-volt power system.
1/26/95	1/26/95	Received 30 tons of WIPP salt. Placed it in the storage tent and took 42, evenly distributed moisture samples. Completed chain of custody documentation and delivered samples to the laboratory.
1/27/95	1/27/95	Put 12 blanket heaters on chamber and moved it near the electrical power distribution panel to facilitate electrical connections.
2/3/95	2/3/95	Placed chamber in the precompacted "hole." Initial chamber attitude showed a northerly dip of 0.5 degree and a westerly dip of 0.3 degree.
		Control code written for 12 tank heaters and three, 15,000-Btu space heaters.
		Compaction chamber designated a "confined space." A sign to this effect posted on the chamber just inside the dome door.
		Void surrounding the chamber (and below ground level) designated a "trench" by SNL inspector.
2/6/95	2/8/95	Constructed wood floor over trench.
		Obtained and installed a zippered door for the salt storage tent.

Start	End	Activities
2/9/95	2/9/95	Checked electrical and computer systems.
		Sandblasted the tamper before painting it.
		Activated heating system.
2/10/95	2/10/95	Wired resistors on the solid-state relays so they will turn off.
2/16/95	2/16/95	Calibrated the three scale weights.
		Took 8 moisture samples from Lift 1, because it has been too long since the original 42 samples were analyzed.
2/17/95	2/17/95	Calibrated the digital scale and sent the two digital thermometers and the thermometer/hygrometer for calibration by the SNL Calibration Laboratory.
		The original (used) computer controlling the heaters failed.
2/24/95	2/24/95	Calibrated the 4' X 8' plywood board used in the high-speed video determination of the terminal velocity of the crane-connected tamper.
		SNL electrical inspectors inspected and approved the 480-volt, electrical generation and distribution system.
2/27/95	2/27/95	**RECEIVED FINAL DOE APPROVAL OF TEST PLAN**
		Heaters off since 2/17/95 due to computer failure.
		Rented conveyor.
		Barricades set up around generator and power distribution panel.
		Barricade set up for spectators at 200' from chamber.
		Warning signs posted on all barricades.
		Steel plates attached to base of dome "ribs" to facilitate the placement of concrete weights (to secure the dome in high winds).

Start	End	Activities
2/28/95	3/2/95	**Loaded Lift 1 and adjusted moisture content.** Dome placed over the compaction chamber. Ordered second truckload of WIPP salt. Leveled salt and returned conveyor.
3/3/95	3/3/95	**Commenced compaction of Lift 1.** Installed safety caps for salt storage rebars (these protrude above the ground approximately 6" and were designated a potential safety hazard during the safety meeting).
3/7/95	3/7/95	Dropped 45 times. Noted that chamber and attached floor are rotating and that conduit passing upward through a rectangular hole in the floor is being bent by hole movement. Become concerned that electrical feed (and temperature probe) wires below the floor may not have sufficient slack to accommodate the rotation (which at this point approximates 12" at the outer edge of the floor). Remove one section of flooring to permit the electricians to add more wire. Discover that all 12, 1.5" diameter bolts securing the chamber cylinder to the base are broken and have fallen out. On one side, the cylindrical chamber has risen approximately 0.75" as determined by hole alignment. No horizontal rotation is noted. Apparently salt is being forced between the base and the bottom of the chamber.
3/8/95	3/10/95	Bracket systems to secure chamber and baseplate are designed. Local fabrication is initiated and several sets are delivered to the test site. The lower band of blanket heaters (4) is removed to facilitate bracket installation by welding. Paint is removed in the bracket locations.

Start	End	Activities
3/13/95	3/14/95	Welding brackets on chamber. SNL construction inspector halts work - requires the installation of shoring in the trench. Contacted shoring company and ordered shoring.
3/15/95	3/15/95	Shoring installed, inspected and approved. Resumed welding of brackets. Installed and activated the anemometer.
3/17/95	3/17/95	**Bracket welding completed.** Took 20, evenly distributed moisture samples from the salt in the storage tent which will constitute Lift 2. Delivered them (with chain of custody documentation) to the lab for analyses.
3/18/95	(Saturday)	Removed shoring. Replaced lower half of polystyrene insulation. Top 6" of the lower four blanket heaters had to be folded away from the chamber to accommodate the brackets. Styrofoam was placed within the folds to prevent the heaters from contacting themselves. Installed bracket bolts, manufactured 70 durometer rubber washers and 0.25" thick steel plates to place over the rubber washers and below the upper nuts. Torqued all bolts to 100 ft-lb.
3/20/95	3/20/95	**Resumed compaction of Lift 1.** Read strain gauges - to obtain a new baseline, following bracket installation (one rosette of gauges was destroyed during the welding operation). Checked bolts at noon - all were loose. Re-torqued all to 100 ft-lb.

Start	End	Activities
3/21/95	3/21/95	Torqued all bolts to 200 ft-lb.
		Dropped 41 times - checked bolts - all were loose. Inserted lock washers and torqued bolts to 600 ft-lb (after checking with the structural engineer). Torqued upper lock nuts to 250 ft-lb.
3/22/95	3/22/95	**Completed compaction of Lift 1.**
		All bolts loose. Retorqued to 600 ft-lb.
		Chamber appears to be settling back onto the base because it is being pulled down by the bracket bolts.
		Leveled salt.
		Commenced loading Lift 2.
3/23/95	3/23/95	Initiated use of small, front-end loader to load salt onto the conveyor.
		Completed loading Lift 2.
		Commenced compaction of Lift 2.
3/24/95	3/24/95	Checked bolts - all had some torque left. Retorqued all to 600 ft-lb.
		3/4 of all floor support planks have split as a result of floor rotation causing pressure against the planks on the chamber end. Made a temporary repair.
3/27/95	3/27/95	Precut new floor support planks.
		Completed compaction of Lift 2.
		Ordered conveyor and sprayer.
		Started construction of new floor, including cable reinforcement.
3/28/95	3/28/95	Completed new floor.

Start	End	Activities
3/29/95	3/29/95	**Loaded Lift 3** (chunks larger than 4" eliminated). These were permitted in Lift #2. Released concrete bucket.
3/30/95	3/30/95	Turned off the generator. Noticed that computer indicated all sensors were disconnected. Removed a section of the floor and saw that everything below the floor was covered with soot but that the floor was not burned. Portions of the lower insulation and heater band were melted. All electrical fuses were okay, i.e., there had been no electrical short. Blanket heaters were tightly wedged between the chamber and base bracket on three sides of the chamber (although when installed, there was clearance on all sides). Apparently the insulation in the folded portion of the heaters melted, dripped onto the top of the base brackets and became hot enough to melt the polystyrene and heater material.
3/31/95	3/31/95	Removed insulation from chamber. Also removed the lower band of blanket heaters and initiated re-wiring of those remaining. Gas flow personnel arrive and began checking their equipment for leaks. Board in the computer has (coincidentally?) failed. All heater circuits are hot at the control panel, but we are unable to get power through the solid state relays. No heating the night of 3/31/95.
4/1/95	(Saturday)	Power hard wired to heaters and all activated. Temperature of the blanket heaters quickly rises to 143°F, which is too hot and they are deactivated. Chamber in the dome is heated over the weekend by three, 15,000 Btu space heaters.
4/3/95	4/3/95	Chamber salt temperature (6" below the top of the powdered salt), taken at 5 positions, is 71.6°F at 7:30 am. **Resumed compaction of Lift #3.**

Start	End	Activities
4/4/95	4/4/95	**Completed compaction of Lift #3.** All bolts had some remaining torque. Retorqued to 600 ft-lb. Positioned crane so it could be used to remove salt from the compaction chamber and dump it in the salt storage area. Chamber now dips 5 degrees to the WNW. Removed approximately 150 cubic feet of powdered salt from the top of the chamber. Salt under the 16" thick layer of powder is like concrete. Bolted diamond drill mount to top of chamber and mounted the drill in the central position. Placed the gas flow trailer on the floor and covered the chamber with the dome. Activated the generator and three space heaters.
4/6/95	4/6/95	Temperature of air in the dome at 8:00 a.m. was 82°F. Diamond drill equipment is not suitable - too much lateral movement at the bit face! The custom mount is solid, but there is too much play in the drill itself and the rods are out of alignment. Modified drill speed with a rheostat to no avail. Gas flow trailer is the only unit on line power. This avoids voltage variation. Drilling equipment produces a very rough hole wall for the initial 32 ± inches - too rough to permit packers to seat. Hole is drilled to 6" above steel base. **Completed gas flow testing of 12' DC-1** and filled it with Hydrastone. Began drilling 12' DC-2.
4/7/95	4/7/95	Completed drilling of 12' DC-2 to the steel base. Began gas flow testing.

Start	End	Activities
4/10/95	4/10/95	Chamber temperature 79°F at 7:30 a.m., and the air in the dome was at 75.1 F, with 2 space heaters on. Completed gas flow testing of 12' DC-2. Initiated drilling of 12' DC-3 (hit steel at 36").
4/11/95	4/11/95	Removed obstruction and completed 12' DC-3 at 6" above steel base. **Completed gas flow testing in 12' DC-3** and filled hole with Hydrastone. Drilled, gas flow tested and sealed hole 12' DC-4.
4/12/95	4/12/95	Drilled, gas flow tested and sealed holes 12' DC-5 and 12' DC-6. Both completed at 6" above steel base. Drilled 12' DC-7 to 6" above steel base and inserted the gas flow tool.
4/13/95	4/13/95	Completed gas flow testing in 12' DC-7. Inspected local crushing plant - it would be feasible to pulverize the salt there if we do another test.
4/17/95	4/18/95	Excavating chamber. Obtain, hermetically seal, and ship three, large blocks of compacted salt (one each from NW, NE and SE quadrants). The top of each is approximately at the top of the compacted powder from Lift 1. These were shipped to RE/SPEC, Inc. in Rapid City, SD with chain of custody documentation on 4/18/95.
4/19/95	5/17/95	Clean all equipment. Clean salt storage tent. Dump 31, 55 gallon barrels of salt from the TDD on the salt pile for shipment to the WIPP. Haul all salt to the spoil pile at the WIPP.

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