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Demolition Range Noise Abatement Technique Demonstration and Evaluation for the McAlester Army Ammunition Plant

James J. Calderone and H. Douglas Garbin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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James J. Calderone
High Consequence Assessment and Technology Department

H. Douglas Garbin
Instrumentation Development Department

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0767

Abstract

Public concern regarding the effects of noise generated by the detonation of excess and obsolete explosive munitions at U.S. Army demolition ranges is a continuing issue for the Army's demilitarization and disposal groups. Recent concerns of citizens living near the McAlester Army Ammunition Plant (MCAAP) in Oklahoma have lead the U.S. Army Defense Ammunition Center (DAC) to conduct a demonstration and evaluation of noise abatement techniques that could be applied to the MCAAP demolition range.

With the support of the DAC, MCAAP, and Sandia National Laboratories (SNL), three types of noise abatement techniques were applied: aqueous foams, overburden (using combinations of sand beds and dirt coverings), and rubber or steel blast mats.

Eight test configurations were studied and twenty-four experiments were conducted on the MCAAP demolition range in July of 2000. Instrumentation and data acquisition systems were fielded for the collection of near-field blast pressures, far-field acoustic pressures, plant boundary seismic signals, and demolition range meteorological conditions. The resulting data has been analyzed and reported, and a ranking of each technique's effects has been provided to the DAC.

Acknowledgements

The authors thank the SNL management team of Lloyd Bonzon, Jane Ann Lamph, Billy Marshall, and Rob Tachau who conceptualized the project. Additionally, those who moved their equipment and brought their expertise to the McAlester Army Ammunition Plant for two weeks deserve a special thank you, especially Paul Johnson, Roger Goode, Mark Naro, Weldon Teague, Robert White, and Raymond O'Connor.

Furthermore, the project could not have succeeded without the coordinated efforts of the DAC and MCAAP. A special thank you goes to Todd Vesely for his leadership, and to Jerry Null, Gary Reasnor, Greg Olsen, and Steve Zdeb for their tremendous support.

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Executive Summary

This report documents the demonstration and evaluation of noise abatement techniques that were applied and studied at the explosives demolition range of the McAlester Army Ammunition Plant (MCAAP).

The summarized results are:

- Both seismic and acoustic signals measured near the boundaries of the MCAAP are orders of magnitude lower than threshold levels deemed to cause minor structural damage or injury to persons.
- The current MCAAP practice of applying an earthen overburden atop explosive materials provides significant noise abatement.
- The alternative noise abatement techniques investigated, while significantly reducing blast pressures near the demolition pits, did not provide appreciable overall reduction of noise levels transmitted beyond the demolition range.
- While other techniques may be worth evaluating, employing the alternative noise abatement techniques demonstrated through this project would not be recommended, based upon the experimental results and the anticipated costs associated with adopting them.

Refer to the Conclusions Section for summary plots of the acoustic data results and Figure 2 for an illustration of the acoustic and seismic measurement station locations.

Acronyms

DAC	Defense Ammunition Center
cm/s	centimeters per second
dB	decibel
ft	feet
g	gram
in.	inch
lb	pounds
m	meter
MCAAP	McAlester Army Ammunition Plant
NEW	net explosive weight
s	second
SNL	Sandia National Laboratories
TNT	trinitrotoluene

Demolition Range Noise Abatement Technique Demonstration and Evaluation for the McAlester Army Ammunition Plant

1. Purpose

The purpose of this project was to demonstrate and evaluate alternative techniques to abate the noise produced by detonating explosive items at the McAlester Army Ammunition Plant (MCAAP) demolition range.

2. Context

The MCAAP includes a demolition range for demilitarizing explosive items. The associated blasts have raised concerns among local citizens regarding noise and blast effects. Sandia National Laboratories (SNL) was tasked to provide an evaluation of noise abatement techniques that could be applied to the MCAAP demolition range. This effort follows two previous monitoring studies, both performed by the U.S. Bureau of Mines [1,2], which concluded that the blast effects could not damage property or injure persons located beyond the plant boundaries.

3. Focus

This project differed from the two previous efforts in two ways. First, it compared existing and alternative noise mitigating techniques, and second, it applied a level of controlled experimental environment. That is, efforts were made to use consistent explosive types and amounts. Furthermore, the resulting sound pressure data was normalized to attempt to remove the potentially significant effects of atmospheric conditions. (For a discussion of the normalizing procedure, see Section 6. Pressure Data Treatment and Normalization of Acoustic Data.)

The following explosive noise abatement techniques were demonstrated and evaluated:

- Modified Overburden,
- Aqueous Foam, and
- Blast Mats.

The ***Modified Overburden*** techniques, an extension of the concept of charge burial, included an enhancement of the existing practice of applying an earthen overburden. One variation involved increasing the overburden while another included applying a bed of sand beneath the explosives and overburden.

Aqueous Foam techniques were applied because of their known ability to attenuate explosive energy and reduce blast pressure [3]. Foaming techniques involve submersing the explosive items with foam. The aqueous foams are attractive for this type of application because they are nonhazardous and the foam-generating equipment is commercially available. The foam experiments included foam of two different densities applied within containment provided by a suspended plastic sheet curtain.

One notable difference between the aqueous foam application and the application of the other techniques is that foam applications replaced the earthen overburden. All other techniques involved combining noise-abating materials with the typical overburden.

The ***Blast Mats*** are used regularly by the blasting and demolition industry to reduce noise and shock and to provide protection from flying debris. Two blast mat types were evaluated, rubber and steel. The rubber mats are heavier and are typically used when few projectiles are expected and noise and blast are to be mitigated, while the steel mats are applied to protect primarily against projectiles. The two blast mat types were employed individually and in combination.

The primary data measured were the acoustic pressures that propagated miles from the demolition range detonations. Closer blast-pressure measurements were made near the individual demolition pits to provide pressure measurements that were unaffected by atmospheric conditions. In addition to recording the acoustic and blast pressure signals created by the detonations, seismic data were also collected. Previous studies have shown that peak ground motion levels produced by blasts at the McAlester Army Ammunition Plant demolition range are well below the value assumed to produce structural damage [1,2]. The present seismic study involved monitoring the ground motion while attempts were made to mitigate the noise from the blast. This was done to ensure that the techniques involved in reducing the acoustic signal do not adversely affect the seismic signal. In addition, because previous seismic work was done with relatively strong motion sensors, only the close-in stations registered measurable ground motion. In this study, very sensitive seismometers were employed to obtain a more quantitative result by detecting the peak signals at these greater ranges.

4. Experiment Procedure

4.1 Overview

Although referred to as pits, the demolition areas are comprised of massive earthen berms amassed above grade level into bowl-shaped structures with an opening on one end of each demolition pit. The pit openings face each other and are in rows on either side of a central road, which is used to transport the explosive items to the demolition pits. The central pit road runs generally from southwest to northeast. Eight demolition pits at the southern end of the row of pits at the “New Demolition Range” were selected for the experimental area. The explosives from each experiment were fired from the firing bunker, Building 495, which is located at the northern end of the road approximately 2000 ft from the experimentation pits. Although the pits can vary in dimensions, typical pit dimensions are shown in Figure 1.

Alternative noise abatement techniques were employed in seven of the pits, leaving one pit for daily “normalization” measurements. Four of the eight pits were instrumented with blast pressure sensors located 33 ft from the center of the explosive charges. Seismic measurements were made in three locations near MCAAP boundaries, and far-field acoustic measurements were made at three stations each approximately 2 miles from the experiment-pit area (see in Figure 2.)

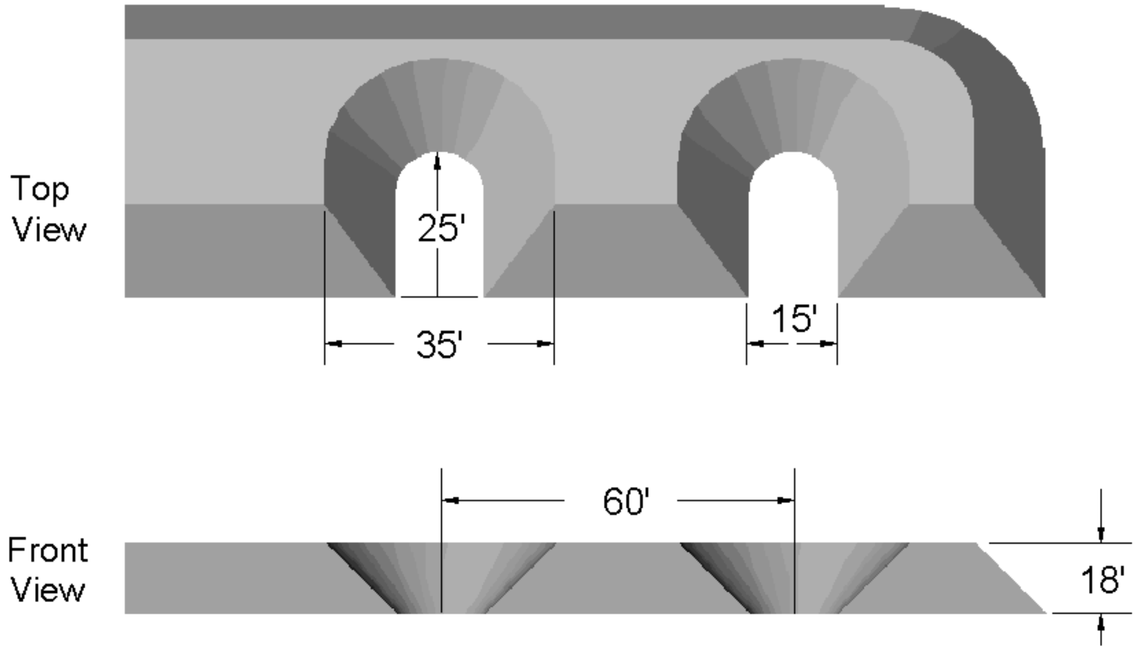

Figure 1. Approximate Demolition Pit Dimensions (feet)

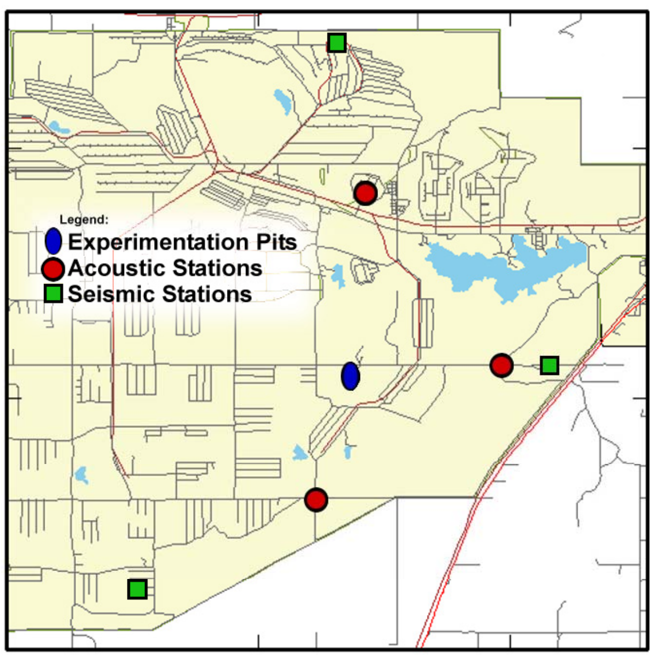

Figure 2. Measurement Station Locations

A portable weather station, Davis Instruments Model 7440EZ, was installed atop the firing bunker, Building 495, to collect meteorological data at the time of firing. The recorded meteorological data included the ambient temperature, wind speed, and approximate wind direction (with an accuracy of 22.5 degrees.) A radio antenna was anchored atop Building 495 and a communication station was set up within the bunker to provide a countdown broadcast to the acoustic stations for manual data-record triggering.

Each experiment involved the detonation of nominally 300 lb of flaked TNT recovered from demilitarization processes. Twenty randomly selected boxes of flaked TNT were carefully weighed to determine the consistency that could be expected from the randomly selected 50-lb boxes that would be used for experimentation. The average TNT box weight was approximately 49.2 lb (related statistics are provided in Appendix A). The boxes were stacked in a three-high by two-wide configuration as shown in Figure 3.

Figure 3. Stacked 50-lb Boxes of Flaked TNT

The experiment philosophy required that at least three experiments were conducted with each alternative technique investigated. This included at least three experiments with far-field acoustic pressure data and at least one experiment with near-field blast pressure data. Another experiment philosophy required that each technique would be studied over at least two days, to allow for any variability due to atmospheric conditions.

4.2 Instrumentation Systems

4.2.1 Acoustic Sensors

Larson-Davis Model 2530 microphones provided flat-weighted, sound-pressure records of each experiment. These acoustic sensors were mounted in pairs on stands (see Figure 4) at two primary locations, nominally north and east of the demolition area, and one secondary location, nominally south of the demolition area. The microphone signals were sent through Larson-Davis Model PRM900B pre-amps and through Larson-Davis Model 2200C power supplies to a 16-bit Quatech Model DAQP-16 data acquisition system. The signals were recorded on laptop computers at a sampling rate of 50k datapoints per second.

The latitude and longitude coordinates for the acoustic and seismic sensor stations, and the experimental area were located with a Global Positioning System (GPS) and are documented in Appendix B.

Figure 4. Acoustic Microphones and Stands

4.2.2 Seismic Sensors

Each seismic station included a three-component Teledyne Geotech GS-13 seismometer and 24-bit REF-TEK units sampling 250 samples per second. Seismic sensor emplacement required digging a hole sufficient to cover the seismometer (2–3 ft in depth and diameter). The gages, shown in Figure 5, were placed on the bottom surface of the hole and leveled. The remaining soil was placed over the sensor and cables were run to the weatherproof box, which contained the digitizers shown in Figure 6.

Figure 5. Teledyne Seismometer

Figure 6. REF-TEK Digitizer

4.2.3 Blast Pressure Sensors

PCB Piezotronics Model 137A23 blast pressure sensors were used to provide an unbiased, direct comparison of the blast pressure of each noise abatement technique. Four experimentation pits (pit numbers 23 through 26) were instrumented with the uni-directional blast pressure sensors. The sensors were directed into the opening of each instrumented pit, at a distance of 33 ft (± 2 in.) from the center of the explosives. Each instrumented pit included redundant sensors for reliability purposes. The blast sensor signals were directed through PCB Piezotronics Model 073A01 Impedance Matching Resistor Modules, and Model 483A power supplies, to LeCroy Model 6810 digitizers and recorders at a sampling rate of 200k datapoints per second. The sensors were mounted on prefabricated 2-ft-tall stands as shown in Figure 7.

Figure 7. Blast Pressure Sensors and Stands

4.3 Noise Abatement Techniques

The following sections discuss each of the alternative noise abatement techniques that were investigated.

4.3.1 Modified Overburden Configurations

All overburden configurations provided an earthen cover over the explosives. The dirt was retrieved and placed with the demolition range's front-end loader, in increments of full buckets. The loader buckets each held approximately 3.5 cubic yards of content. FThe overburden dirt was relatively clean soil excavated from the end of the demolition range berm.

Another investigated overburden modification was the addition of a bed of sand beneath the explosives. In an effort to avoid introducing additional heavy equipment for excavation, the sand was placed on the floor of the experimental pit prior to placing the explosives. The sand was clean local sand.

The following Modified Overburden types were investigated:

4.3.1.1 "Typical" Two Buckets of Dirt

The demolition range operating personnel previously identified a typical noise mitigation effort for 300 lb of explosives to be two loader buckets of dirt placed over the explosive items. This prescription became the standard configuration to which all other techniques would be compared. Figure 8 shows a "'typical' two buckets of dirt" setup.

Figure 8. "Typical" Two Buckets of Dirt

The average setup for this configuration resulted in a total pile height of 5.25 ft, which provided a cover depth of approximately 3.5 ft of dirt to the top of the explosives.

4.3.1.2 Four Buckets of Dirt

This setup was identical to the "typical" dirt configuration with the exception of doubling the amount of dirt cover to four buckets. This provided additional dirt cover resulting in a depth of cover of 4.3 ft. A "four buckets of dirt" setup is shown in Figure 9.

Figure 9. Four Buckets of Dirt

4.3.1.3 One-Bucket Bed of Sand

This modification of the overburden technique involved placing a single-bucket bed of sand beneath the explosive charge, followed by the typical cover of two buckets of dirt atop the charge, as shown in Figure 10 and Figure 11.

This configuration provided an average sand depth of 15 in. The average dirt-pile height of 6.5 ft resulted in an average dirt cover of 3.5 ft.

4.3.1.4 Two-Bucket Bed of Sand

This setup was identical to the previous sand configuration except that using two buckets of sand created a larger, deeper sand bed as shown in Figure 12 and Figure 13.

This configuration provided an average sand depth of 33 in. The average dirt pile height of 6.5 ft resulted in a dirt cover depth of only 2.0 ft. The limited depth of dirt cover results from the fact that as the pile size increases, so does its surface area. That is, since the pile surface area increases as the pile increases, each added bucket spreads over a larger area, which reduces the incremental depth of cover of each bucket.

Figure 10. One-Bucket Bed of Sand

Figure 11. One-Bucket Bed of Sand beneath Two Buckets of Dirt

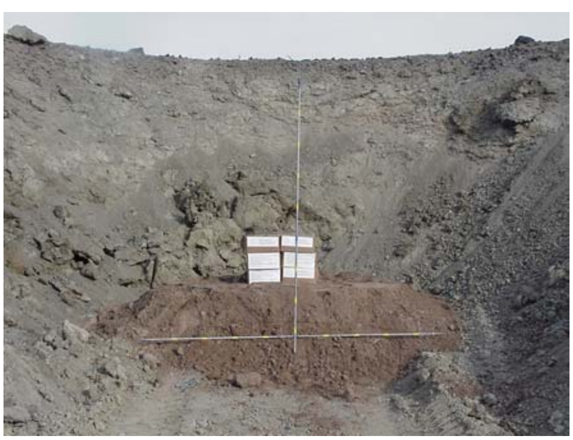

Figure 12. Two-Bucket Bed of Sand

Figure 13. Two-Bucket Bed of Sand beneath Two Buckets of Dirt

4.3.2 Aqueous Foam Configurations

Aqueous foam predominately consists of water. A foam concentrate is mixed with water in a 6% weight concentration and air is introduced to create foam. The foam concentrate consists of deionized water with a surfactant and a polymer stabilizer, which combine to form essentially soapy water. The solution is pumped to a foam generator, where ambient air is aspirated through a mesh or screen, along with the soapy water, to create the stable foam.

Foam "quality" for this application is related to its density, or more specifically, its expansion ratio. The expansion ratio is the volumetric ratio of foam to the liquid in the foam. Two different foam generators were used to create foams of two different densities.

The foamed demolition pits required containment of the foam. This was accomplished with the suspension of a nylon-fiber reinforced plastic curtain across the opening of the pit. The plastic curtain was attached to a wire rope strung across the top of the pit entrance and was anchored, with stakes, to the pit walls and floor. The foam was introduced to the pit from atop the berm wall surrounding the pit, as shown in Figure 14.

Figure 14. Applying Aqueous Foam

As previously noted, the foam was applied directly over the explosives to submerse them in foam. The distances from the center of the explosives to the outer foam surfaces, varying between 7 and 15 ft, were difficult to control as a result of the variability of the slopes of the pit walls and floors.

4.3.2.1 Medium-Density Aqueous Foam

The medium-density foam, with an approximate expansion ratio of 120:1, was generated using an MSA Model 3000 Foam Generator, as shown in Figure 15.

Figure 15. Medium-Density Aqueous Foam

4.3.2.2 High-Density Aqueous Foam

The high-density foam, with an expansion ratio of approximately 45:1, was generated with an MSA Type IV Foam Generator. A typical high-density foamed pit is shown in Figure 16.

Figure 16. High-Density Aqueous Foam

4.3.3 Blast Mat Configurations

Three blast mat configurations were applied with two different types of blast mats. The mat types were essentially rubber mats and steel mats. The rubber and steel mats were applied individually and in combination. The dimensions of each mat were approximately 12 × 12 ft. The rubber mats were approximately 1 ft thick and the steel mats were about 8 in. thick. The site operating personnel placed the mats with existing site equipment.

The following blast mat configurations were investigated:

4.3.3.1 Rubber Blast Mats

The Rubber Blast Mats, ARMAG Model 35SB-12, weighed approximately 5200 lb, and were constructed of rubber tire sections woven with steel wire rope. The rubber mat was placed atop the typical earthen overburden, as shown in Figure 17.

Figure 17. Rubber Blast Mat

4.3.3.2 Steel Blast Mats

Steel Blast Mats, ARMAG 5/8-inch Wire Rope models, weighed approximately 2600 lb, and were constructed of woven steel wire rope recovered from elevator applications. The steel mat was placed atop the typical earthen overburden, as shown in Figure 18.

Figure 18. Steel Blast Mat

4.3.3.3 Steel and Rubber Blast Mat Combination

One rubber and one steel mat were combined to form two mat layers. The rubber mat was placed above the steel mat. The mat combination was placed over the typical earthen overburden, as shown in Figure 19.

Figure 19. Combined Steel and Rubber Blast Mats

4.4 *Experiment Sequence*

4.4.1 Experiment Day One

The experimentation pit configuration for the first day of experiments (July 15, 2000) is shown in Figure 20. Instrumented pits are noted. The pit labeled "standard" indicates the pit that was used for normalization data.

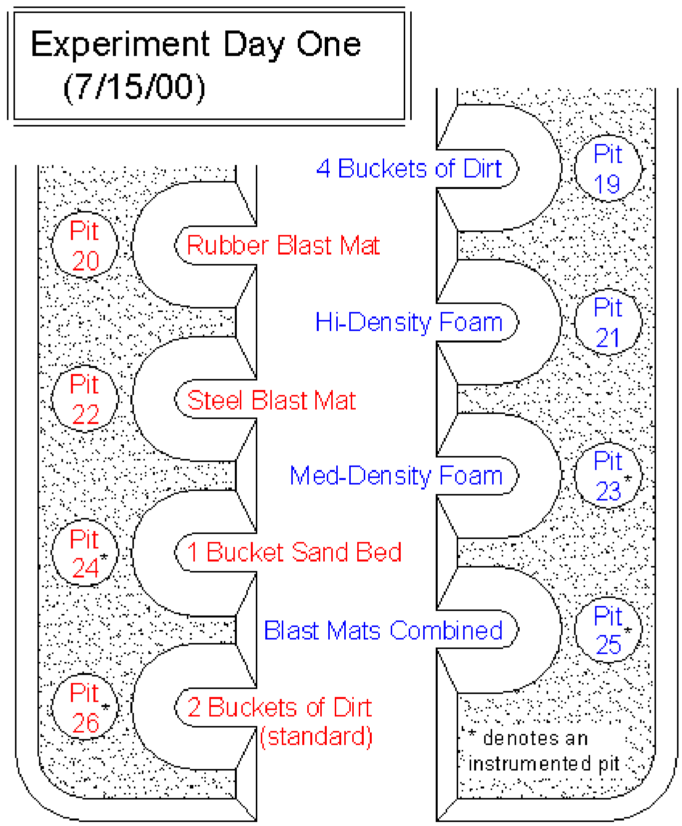

Figure 20. Pit Configuration for Experiment Day One (7/15/00)

4.4.2 Experiment Day Two

The outcome of the Day One experiments resulted in the following modifications for Day Two:

1. Further blast mat experiments were precluded as a result of their destruction on Day One, leaving three additional experimentation pits available for other study.

2. One of the available additional pits was used to establish "standard" pits on both sides of the pit row to investigate the effect, if any, of differing sides of the pit row. This was done to ensure that potential focusing effects of the pits did not influence the acoustic readings at different locations.

3. Without additional hardware or personnel available to provide more than two foamed pits, the additional available pits could not be used to increase the scope of foaming studies. However, uncharacteristically high blast pressure results from the instrumented medium-density foamed pit prompted the focusing of efforts on the high-density foam for the remaining instrumented foam experiments.

4. The remaining two available additional pits were used to study other Modified Overburden options. A second four-bucket earthen cover experiment was added, and a larger two-bucket sand bed experiment was added.

The resulting pit configuration for Day Two is shown in Figure 21.

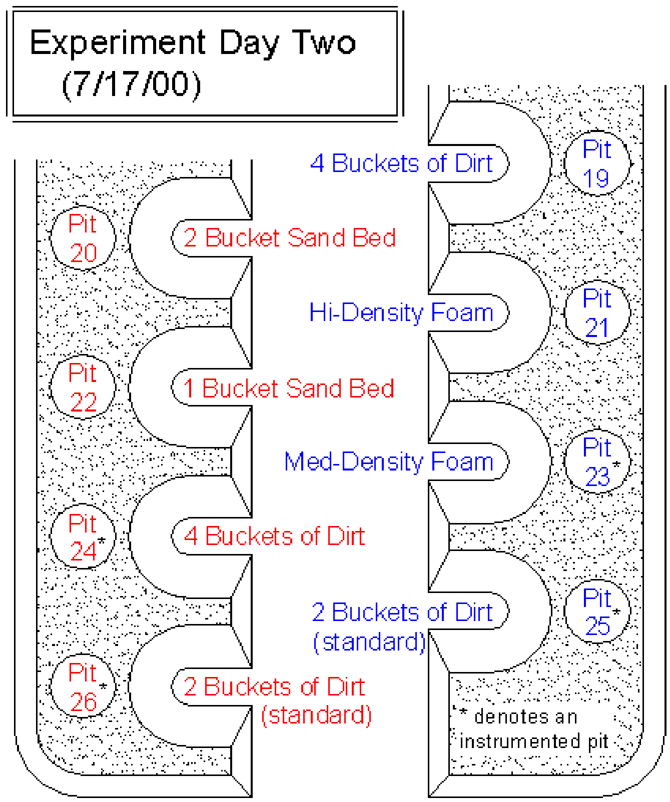

Figure 21. Pit Configuration for Experiment Day Two (7/17/00)

4.4.3 Experiment Day Three

A quick review of the data from the first two days of experiments showed that the MCAAP standard practice was a good noise abatement technique. There was only a marginal difference between the pressures produced by the standard pits, and those produced by the alternative techniques. As a result, the decision was made to study bare, uncovered TNT to provide baseline data. The experimentation pit configuration for the third day of experiments, July 18, is shown in Figure 22.

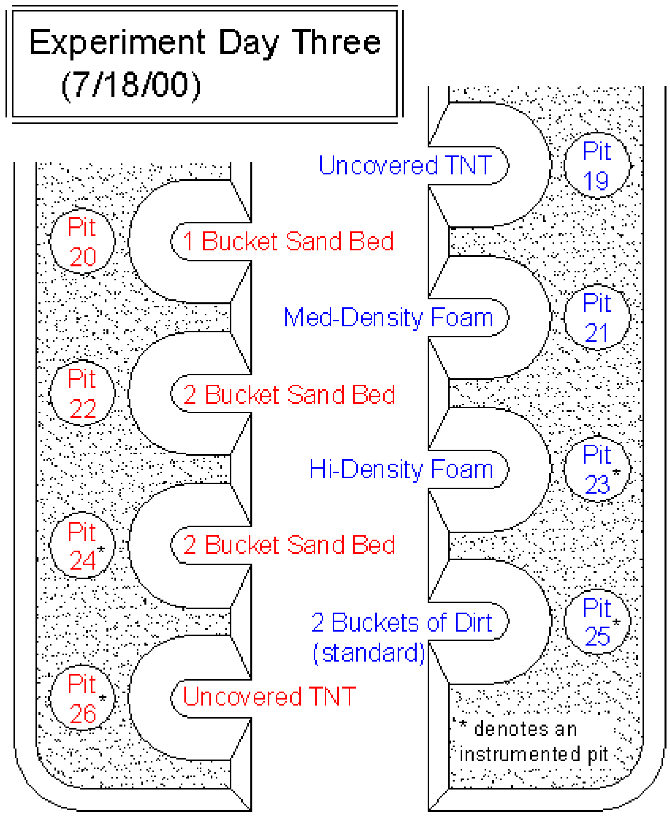

Figure 22. Pit Configuration for Experiment Day Three (7/18/00)

5. Results

5.1 Acoustic Data

Acoustic data were gathered from each recording station and analyzed for the peak pressures. A representative acoustic signal is shown in Figure 23. The resulting acoustic peak pressure values recorded during the experiments are shown in tabular form in Figure 24, along with meteorological measurements. The corresponding peak Sound Pressure Levels are shown in Figure 25.

Acoustic measurements were also recorded with MCAAP equipment at stations located near population clusters. Since measurements at these stations are only recorded when signals exceed a variable minimum threshold, continuous data was only recorded at the closest station located at the MCAAP gate. These data are compared (in Appendix C) to the corresponding Sandia data recorded by equipment located along a similar path, but closer to the detonation events and at a consequently higher pressure level. Additionally, a qualitative review of the acoustic pressure data demonstrated a significant and consistent dependence upon wind direction and speed, as would be expected.

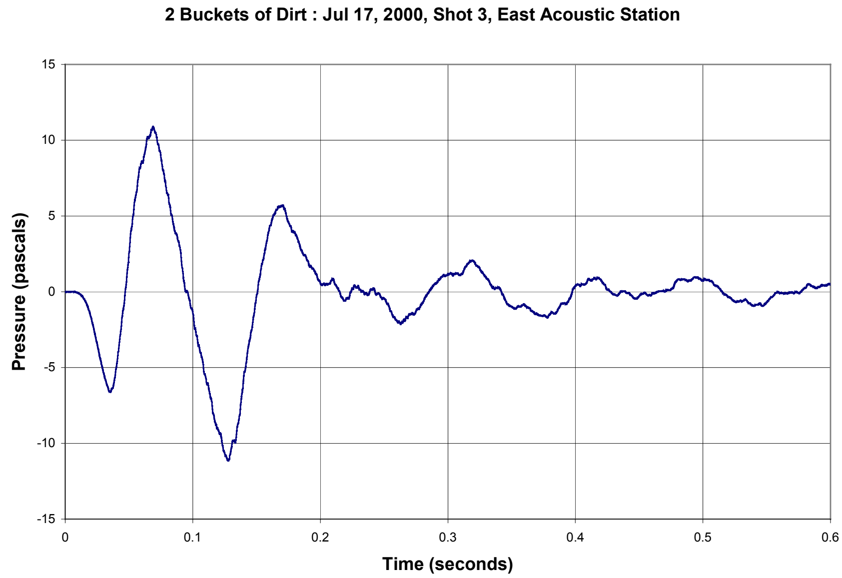

Figure 23. Representative Acoustic Signal

	Date	Shot	Pit	Acoustic Pressure Peak (Pascals) North Station	East Station	South Station	Wind Direction	Wind Speed (mph)	Temperature (degrees F)	Time
Aqueous Foam: Med-Density	7/15/00	2	23	18.3	43.0	11.0	SSE	11	91	11:34:20
	7/17/00	2	21	14.8	17.7	36.4	ENE	6	89	11:53:20
	7/18/00	2	21	20.1	53.5	no data	SSE	16	90	11:04:20
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Aqueous Foam: Hi-Density	7/17/00	1	23	13.5	12.0	17.9	ENE	7	89	11:52:10
	7/15/00	1	21	21.6	28.8	8.8	SSE	8	91	11:32:40
	7/18/00	1	23	16.3	27.2	no data	SSW	14	89	11:03:20
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Sand: 1 Bucket Bed (w/ standard overburden)	7/15/00	5	24	11.1	33.4	8.2	SSE	10	91	11:39:20
	7/17/00	6	22	9.7	19.5	29.7	ENE	5	90	11:58:10
	7/18/00	6	20	12.3	28.1	no data	SSW	16	89	11:14:10
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Dirt: 4 Buckets	7/17/00	5	24	6.6	12.4	20.0	ENE	7	90	11:56:30
	7/15/00	7	19	8.4	13.3	4.0	SSE	6	91	11:41:30
	7/17/00	8	19	8.9	14.0	16.3	ENE	5	90	12:00:10
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Blast Mat: Rubber	7/15/00	8	20	7.0	no data	8.3	SSE	10	91	11:43:10
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Blast Mat: Steel	7/15/00	6	22	8.4	33.6	7.5	SSE	12	91	11:40:30
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Blast Mat: Steel & Rubber	7/15/00	4	25	6.8	16.0	5.7	SSE	14	91	11:37:40
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Dirt: 2 Bucket (standard)	7/15/00	3	26	7.0	26.1	8.8	SSE	10	91	11:36:20
	7/17/00	3	25	12.6	11.1	22.5	ENE	6	89	11:54:20
	7/17/00	4	26	8.5	13.9	19.7	ENE	6	90	11:55:30
	7/18/00	3	25	13.1	17.6	no data	SSW	16	90	11:05:20
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
Sand: 2 Bucket Bed (w/ standard overburden)	7/18/00	4	24	12.9	45.2	no data	SSW	19	90	11:06:20
	7/17/00	7	20	9.7	30.3	41.0	ENE	5	90	11:59:10
	7/18/00	5	22	10.6	68.0	no data	SSW	17	90	11:13:10
	Date	**Shot**	**Pit**	**N. Sta.**	**E. Sta.**	**S. Sta.**	**WD**	**WS**	**Temp**	**Time**
TNT: Uncovered	7/18/00	8	26	19.6	71.4	no data	SSW	17	91	12:17:50
	7/18/00	7	19	29.8	70.7	no data	SSE	13	90	11:34:50

Figure 24. Table of Peak Acoustic Pressure

	Date	Shot	Pit	Sound Pressure Level Peak (dB) North Station	East Station	South Station	Wind Direction	Wind Speed (mph)	Temperature (degrees F)	Time
Aqueous Foam: Med-Density	7/15/00	2	23	119.2	126.6	114.8	SSE	11	91	11:34:20
	7/17/00	2	21	117.4	118.9	125.2	ENE	6	89	11:53:20
	7/18/00	2	21	120.0	128.5	no data	SSE	16	90	11:04:20
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Aqueous Foam: Hi-Density	7/17/00	1	23	116.6	115.6	119.0	ENE	7	89	11:52:10
	7/15/00	1	21	120.7	123.2	112.9	SSE	8	91	11:32:40
	7/18/00	1	23	118.2	122.7	no data	SSW	14	89	11:03:20
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Sand: 1 Bucket Bed (w/ standard overburden)	7/15/00	5	24	114.9	124.5	112.3	SSE	10	91	11:39:20
	7/17/00	6	22	113.7	119.8	123.4	ENE	5	90	11:58:10
	7/18/00	6	20	115.7	123.0	no data	SSW	16	89	11:14:10
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Dirt: 4 Buckets	7/17/00	5	24	110.4	115.8	120.0	ENE	7	90	11:56:30
	7/15/00	7	19	112.5	116.5	106.0	SSE	6	91	11:41:30
	7/17/00	8	19	113.0	116.9	118.2	ENE	5	90	12:00:10
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Blast Mat: Rubber	7/15/00	8	20	110.9	no data	112.4	SSE	10	91	11:43:10
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Blast Mat: Steel	7/15/00	6	22	112.5	124.5	111.5	SSE	12	91	11:40:30
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Blast Mat: Steel & Rubber	7/15/00	4	25	110.6	118.1	109.1	SSE	14	91	11:37:40
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Dirt: 2 Bucket (standard)	7/15/00	3	26	110.9	122.3	112.9	SSE	10	91	11:36:20
	7/17/00	3	25	116.0	114.9	121.0	ENE	6	89	11:54:20
	7/17/00	4	26	112.6	116.8	119.9	ENE	6	90	11:55:30
	7/18/00	3	25	116.3	118.9	no data	SSW	16	90	11:05:20
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
Sand: 2 Bucket Bed (w/ standard overburden)	7/18/00	4	24	116.2	127.1	no data	SSW	19	90	11:06:20
	7/17/00	7	20	113.7	123.6	126.2	ENE	5	90	11:59:10
	7/18/00	5	22	114.5	130.6	no data	SSW	17	90	11:13:10
	Date	Shot	Pit	N. Sta.	E. Sta.	S. Sta.	WD	WS	Temp	Time
TNT: Uncovered	7/18/00	8	26	119.8	131.1	no data	SSW	17	91	12:17:50
	7/18/00	7	19	123.5	131.0	no data	SSE	13	90	11:34:50

Figure 25. Table of Peak Sound Pressure Level

5.2 Seismic Data

The seismic signal from a typical shot sequence is shown in Figure 26. These plots are vertical component signals recorded at ranges of approximately 4100, 6700, and 8300 m from the pits. Figure 27 is a plot of the eastern station labeled with the various sources. These particular data were collected on July 17 from the 300 lb charges. There were eight explosions within a time interval of less than ten minutes. Each event occurred about a minute apart. Associated with each seismic arrival was an acoustically induced seismic arrival. An expanded view of the standard event is shown in Figure 28 and illustrates the two signals. If the seismic velocity is assumed to be 4300 m/sec, with an associated acoustic velocity of 340 m/s, then the signal arrivals are about 11 seconds apart. This is approximately the case in Figure 28. The acoustically induced seismic signal is normally the larger signal. It should be noted that there is a 110-Hz anti-aliasing filter in the REF-TEK units, thus the acoustically induced signals do not have the high frequency content of acoustic signals. In addition, the seismometer responses are flat to velocity from 1 to 100 Hz and falls off at higher frequencies. These induced amplitudes are in general higher than the pure seismic signals. In spite of this, the maximum generated amplitudes are all two to three orders of magnitude beneath the 5 cm/s threshold deemed to cause minor damage or the 1.25 cm/s threshold suggested by the U.S. Bureau of Mines [4]. Figure 29 lists the average peak-to-peak (p-p) amplitudes of all the shots in the experiment.

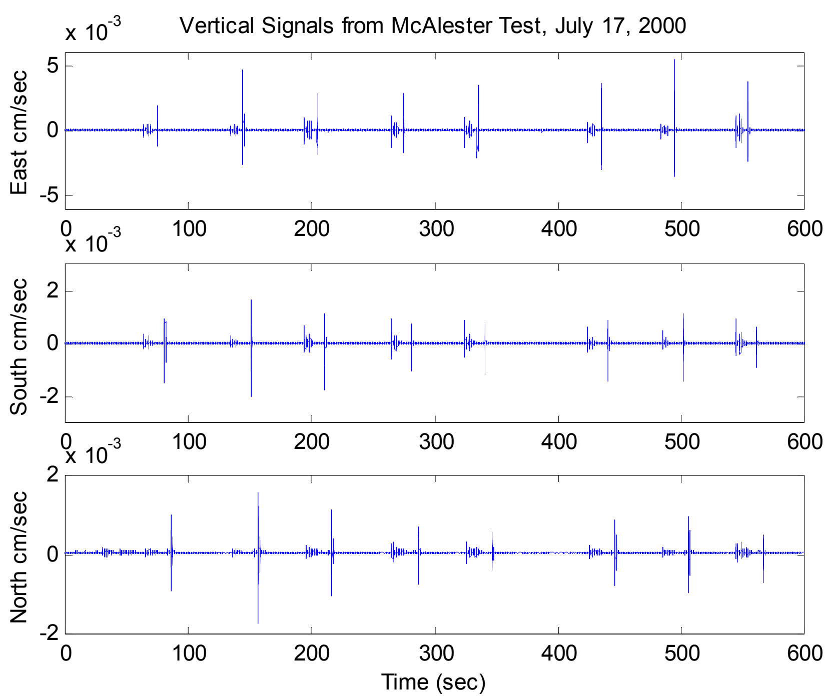

Figure 26. Representative Vertical Seismic Signals

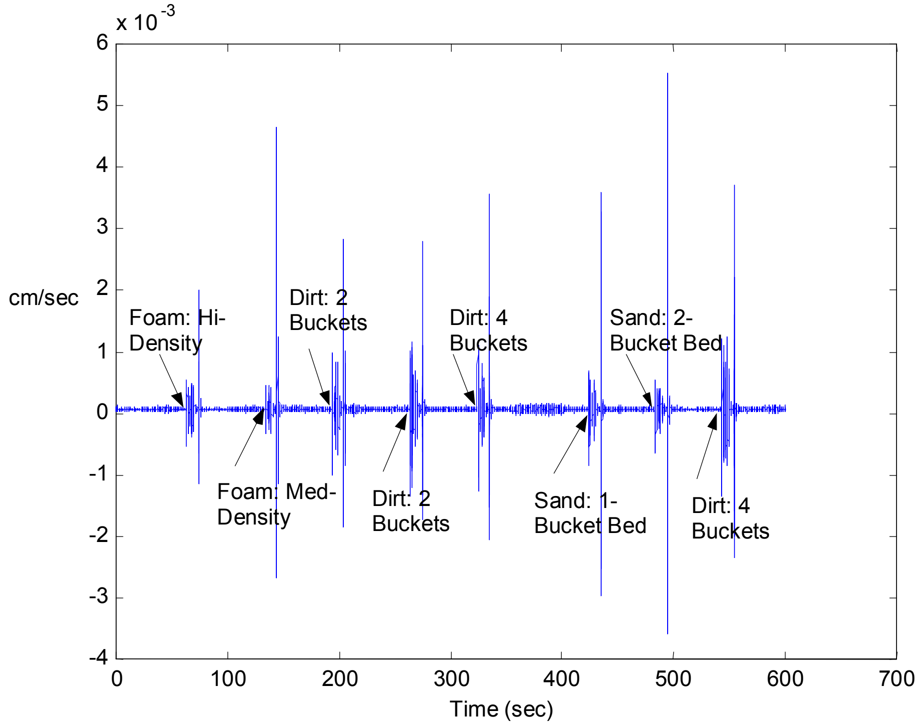

Figure 27. Vertical Ground Motion at East Station (7/17/00)

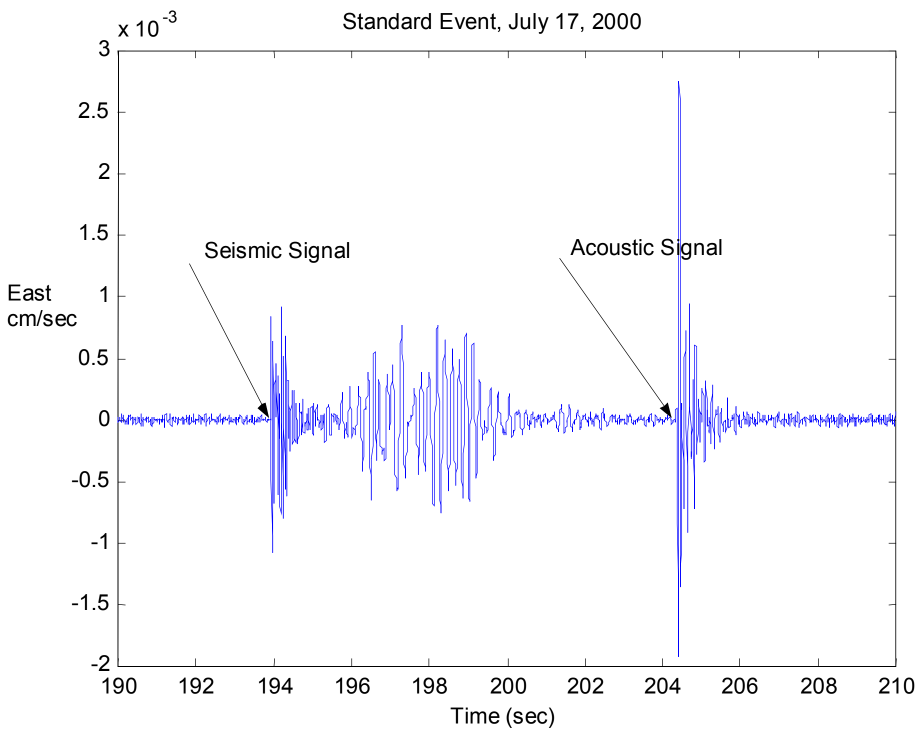

Figure 28. Standard Event Seismic Signal (7/17/00)

		Seismic	Acoustic
Dirt:	**2-Buckets**	0.002384	0.009017
	4-Buckets	0.002500	0.006050
Blast Mat:	**Rubber**	0.001932	0.011499
	Steel	0.001864	0.021065
	Steel & Rubber	0.002376	0.009720
Aqueous Foam:	**Hi-Density**	0.001010	0.011090
	Med-Density	0.000890	0.015100
Sand Bed:	**1-Bucket**	0.001500	0.010940
	2-Buckets	0.001300	0.013780

Figure 29. Average Peak-to-Peak Amplitudes of All Tests (cm/s)

The measurements made by the horizontal sensors are similar to the vertical components. In all cases, this illustrates that the seismic signals are at least two orders of magnitude lower then the 1.25 cm/s threshold. From this data, the seismic signals are not increased by the various mitigating factors introduced to reduce the acoustic signals.

5.3 Blast Pressure Data

Blast pressure measurements were recorded during each day of experiments. A typical blast pressure signal is shown in Figure 30, and a table of peak blast pressure for all blast-pressure measurements is given in Figure 31.

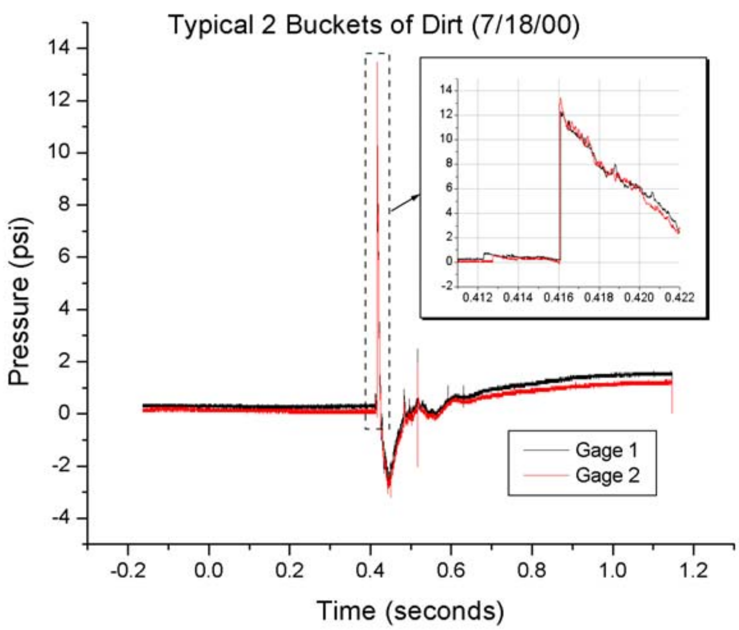

Figure 30. Representative Blast Pressure Signal

All blast pressure signals appeared valid except those from demolition pit 23, which involved the foam experiments. Several publications provide information that may be used to predict the expected level of blast pressure resulting from detonations that have been mitigated by aqueous foams. The tool used to make predictions for these experiments was the NEST calculator [5]. For a medium-density foam of 12 ft depth, the resulting pressure at the blast-pressure gages would be between 6.4 and 8.1 psi. depending on the applied TNT equivalence of Composition C-4. Similarly, with a high-density foam, pressures between 2.5 and 3.3 psi would be expected. Review of data from these experiments shows a blast pressure of 2 to 7 times what would have been expected. One possible explanation for the discrepancies is that the geometry of the pit would not allow uniform distribution of the foam around the explosives, and that the pit geometry may have actually focused the blast energy.

Although these results suggest that the foam blast pressure data may be questionable, it has been reported as it was recorded since this would have no effect on the more important acoustic data.

	Date	Shot	Pit	Blast Pressure (psi) Gage 1	Gage 2	Wind Direction	Wind Speed (mph)	Temperature (degrees F)	Time
Aqueous Foam: Med-Density	7/15/00	2	23	40.23	46.49	SSE	11	91	11:34:20

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Aqueous Foam: Hi-Density	7/17/00	1	23	6.02	5.81	ENE	7	89	11:52:10
	7/18/00	1	23	6.79	6.67	SSW	14	89	11:03:20

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Sand: 1 Bucket Bed (w/ standard overburden)	7/15/00	5	24	12.47	12.17	SSE	10	91	11:39:20

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Dirt: 4 Buckets	7/17/00	5	24	8.76	9.15	ENE	7	90	11:56:30

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Blast Mat: Rubber	7/15/00	8	20	X	X	SSE	10	91	11:43:10

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Blast Mat: Steel	7/15/00	6	22	X	X	SSE	12	91	11:40:30

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Blast Mat: Steel & Rubber	7/15/00	4	25	2.56	2.68	SSE	14	91	11:37:40

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Dirt: 2 Bucket (standard)	7/15/00	3	26	8.71	8.91	SSE	10	91	11:36:20
	7/17/00	3	25	8.96	8.33	ENE	6	89	11:54:20
	7/17/00	4	26	9.00	9.25	ENE	6	90	11:55:30
	7/18/00	3	25	12.02	13.32	SSW	16	90	11:05:20

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
Sand: 2 Bucket Bed (w/ standard overburden)	7/18/00	4	24	14.12	14.65	SSW	19	90	11:06:20

	Date	Shot	Pit	Gage 1	Gage 2	WD	WS	Temp	Time
TNT: Uncovered	7/18/00	8	26	75.27	52.77	SSW	17	91	12:17:50

Figure 31. Peak Blast Pressure

6. Pressure Data Treatment and Normalization of Acoustic Data

The influence of atmospheric conditions on the propagation of acoustic signals has been studied extensively. Atmospheric blast focusing can increase overpressures by 3 to 5 times [6]. Although careful measurement of atmospheric conditions may be combined with sophisticated computer models to attempt to predict atmospheric influences, this would have required significant time and investment to implement. For the purposes of these studies, rather than attempting to account for atmospheric effects, the data was normalized to attempt to eliminate atmospheric effects. A description of the normalization process follows.

Each day experiments were performed, the experiment pits were fired sequentially, typically within one minute of each other. This limited the time interval, which reduced the likelihood that atmospheric conditions could significantly change. Additionally, each experimental series included an instrumented pit containing the "typical" two buckets of dirt overburden as the standard. Peak acoustic pressure values recorded for the experimentation pits were divided by the peak pressure values recorded for the "standard" pit for each experiment series and each separate acoustic station. For example:

> Consider the north acoustic station, medium-density aqueous foam measurement from July 15th. The measured pressure, from Figure 24, is 18.3 pascals. The "standard" pit measurement for July 15th is 7.0 pascals (also from Figure 24) Dividing the north station pressure by the standard measurement gives a value of approximately 2.6. This implies that the pressure propagated from the medium-density foam pit was 2.6 times higher than the pressure propagated from the "standard" pit, resulting in a normalized value of 260%.

This procedure normalized the data to attempt to cancel the atmospheric effects, or at least significantly reduce their effects. The reasoning behind this data treatment is that the influence of the atmosphere on data from any experiment pit would be the same influence affecting the data from the "standard" pit, therefore, the ratioing of the two values negates the common atmospheric influence. This data treatment also allows for reasonable comparison of data taken on different days, since data from each day were normalized to attempt to negate the day-to-day atmospheric conditions. All normalized acoustic pressure data for each noise abatement technique is shown in Figure 32.

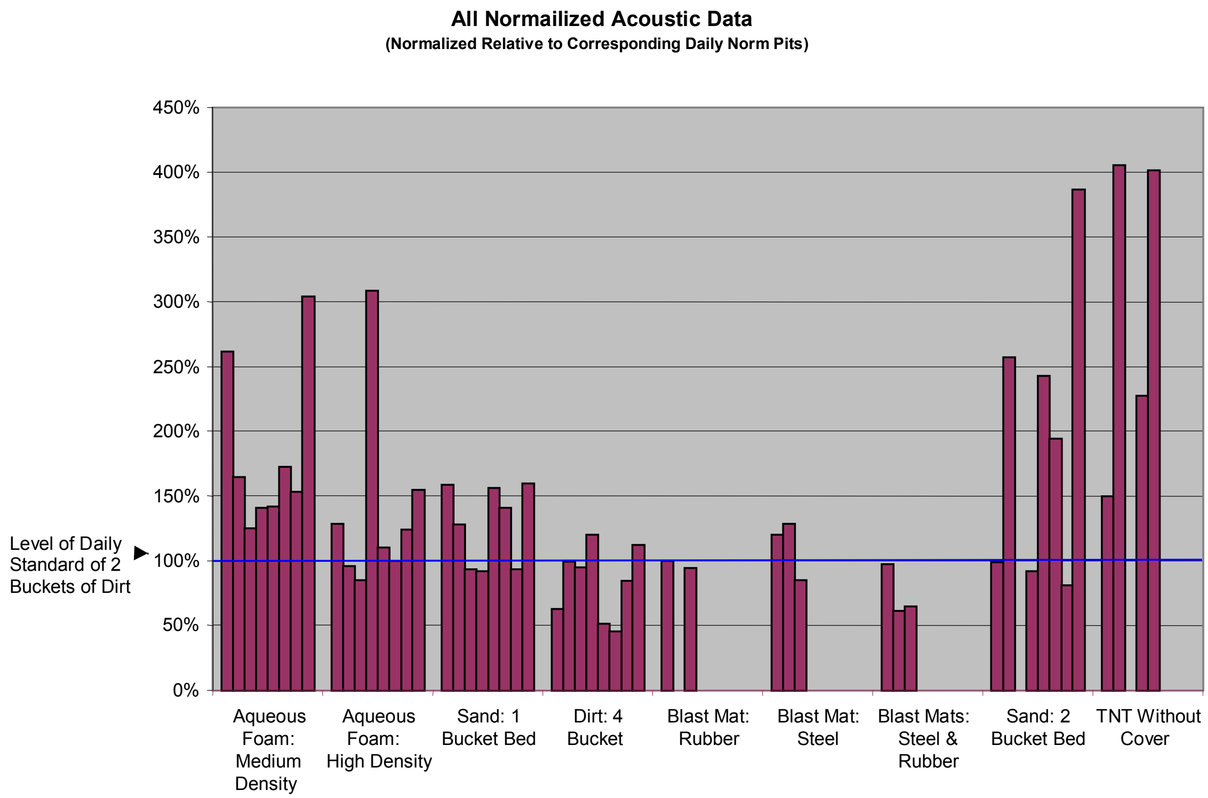

Figure 32. All Normalized Acoustic Data by Technique

The blast pressure sensors, located 33 ft from the explosives, would receive negligible influence from atmospheric conditions over the duration of the series of experiments. As a result, this data did not require that normalization of the blast pressure data be limited to a specific test series day, but rather that the data could be used in comparisons across the whole experiment series.

7. Conclusions

The MCAAP typical practice of applying two loader buckets, approximately 7 cubic yards, of earthen overburden provides significant noise abatement relative to uncovered explosives. Figure 33 shows the percentage of TNT peak pressures, both near-field blast and far-field acoustic, for the normal MCAAP overburden along with the alternative techniques investigated through this study. Note that the “standard” practice provides an almost two-thirds reduction in peak acoustic pressure.

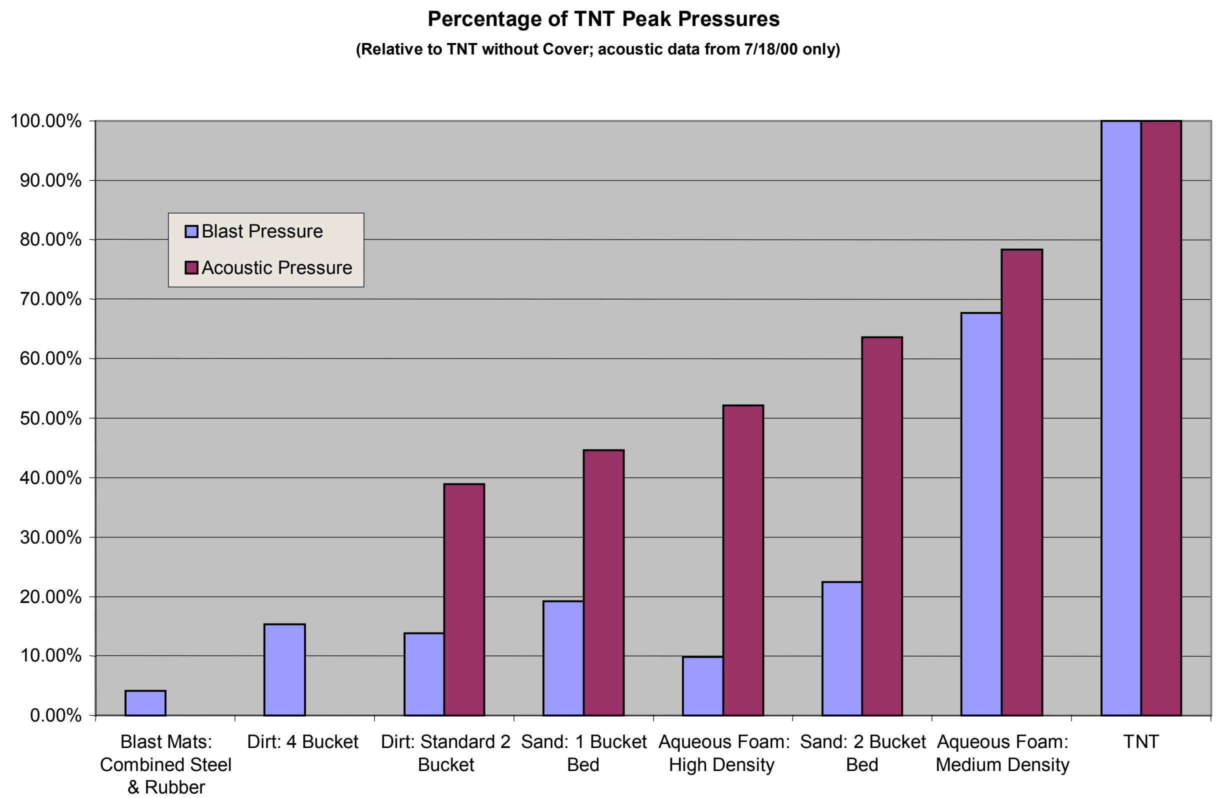

Figure 33. Abatement Technique Percentage of TNT Peak Pressure

A comparison of the alternative noise abatement techniques and the uncovered TNT data is provided in Figure 34. This figure shows a ranking of average acoustic peak pressures of the alternative techniques viewed relative to the standard. While the combination blast mat configuration showed favorable acoustic pressure reductions, they were destroyed in one shot and therefore would be a disposable item. At a combined cost of nearly $5K per pit per day, they could not be recommended for implementation.

A 17% reduction in acoustic pressure was obtained by the doubling of earthen overburden to 4 buckets. While this is one of the better alternatives, a 17% reduction in peak sound pressure is less than a 2 decibel (dB) reduction in sound pressure level. Normal human hearing cannot detect a 2-dB change in sound level [7].

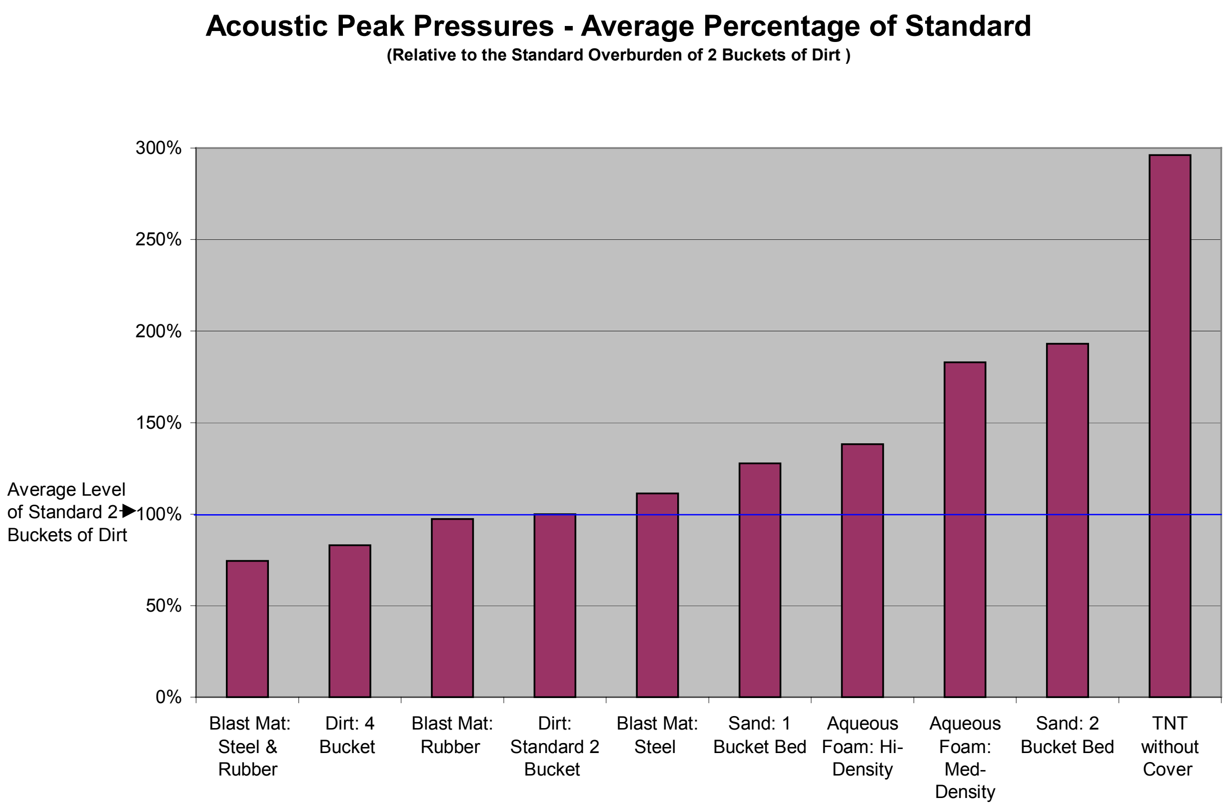

Figure 34. Acoustic Peak Pressure - Comparison of Techniques

8. Recommendations

Overburden techniques provide significant acoustic pressure reductions and are elegant in their simplicity. These techniques already provide significant noise reduction and neither the acoustic pressure levels nor the seismic signature levels are even marginally close to established standards for human or structural damage [4,8].

1) One variation of this technique that was generally discussed, but was not tried due to significant operational questions, is the burial of the explosive items. This would require major heavy equipment and creates operational safety issues, but it may provide a useful solution that would be an improvement over allowing firings to be limited by atmospheric conditions.

   Some of the considerations that may need to be addressed prior to evaluating or implementing this technique would be:

   a) How would operators place the explosive items into the hole?
   b) When would operators place donor charges with the explosive items?
   c) What operations would be required in a misfired buried explosive scenario?
   d) Does the soil eventually become so loosely packed that it can only sustain a finite number of detonations before it must be re-packed?

2) If the nuisance of repetitive sound disturbances is the greater problem, then a more sophisticated firing system providing a ripple-fired detonation sequence may offer opportunities to provide a less annoying environment. Rather than the current sequence of repetitive firings over several minutes, a single pulse of longer duration, possibly less than 15 seconds, may be a lesser nuisance. This would project a single "roar" rather than repeated "bangs." Implementing this technique would require some up-front attention to designating a favorable timing interval to be certain that the blast-generated acoustic pressures did not constructively combine to increase the overall peak pressures propagated beyond the MCAAP boundaries. Optimally, this technique could significantly reduce the overall sound pressures propagated from the range.

   Acoustic data collected from these experiments could be useful in determining a timing sequence by allowing the study of the consistency of frequency content of the acoustic signals followed by the selection of an appropriate timing interval that reduces the combined pressures of the sequential blasts. A cursory review of the existing acoustic data indicates a fairly consistent dominant frequency, which is promising for this type of solution. This option could offer a considerable effect without significant cost, or any affect on range throughput.

3) A third, but operationally less attractive solution alluded to in previous sections, would be to collect atmospheric information to be fed into sophisticated computer models to attempt to predict sound levels at various locations. While these models may aid in predicting where focusing of sound energy may occur, they have the disadvantage that they may require additional staffing to operate and maintain the equipment, and they could have a detrimental effect on demolition range throughput.

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Appendix A: Average Weight of TNT Boxes

To determine the expected variation of explosives quantities used in these experiments, 20 of the 50-lb boxes of recovered, flaked TNT were weighed. A tare weight was obtained from a representative box, and the resulting net explosive weight (NEW) for each box is shown in the table below.

McAAP Flaked TNT 50 lb Box Weights - 7/12/00

Weight(g) *	NEW(lb)	Box Wt.(g)
23190	46.68	2018
23189	46.67	
23300	46.92	
23360	47.05	
24195	48.89	
23825	48.08	
23430	47.21	
23320	46.96	
26484	53.94	
23290	46.90	
24790	50.20	
22496	45.15	
25989	52.85	
24606	49.80	
24645	49.88	
26452	53.87	
28324	57.99	
23359	47.05	
24981	50.62	
23698	47.80	
Average=>	49.23	
StdDev=>	3.24	
%StdDev=>	6.59	
Min=>	45.15	
Max=>	57.99	

* In box in plastic bag

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Appendix B: Measurement Stations by Latitude and Longitude

The indicated position measurements are given in degrees, minutes, and seconds.

Acoustic Stations

	N Latitude	W Longitude	
North Acoustic Station	34 52 03.7	95 55 02.4	<= Used during some calibration tests
North Acoustic Station	34 50 56.9	95 54 24.4	<= Used during experiments
East Acoustic Station	34 48 39.7	95 52 36.0	
South Acoustic Station	34 46 56.3	95 55 02.2	
495 Bunker (@ Weather Station)	34 48 41.2	95 54 29.0	
Experiment Pits (Approx Center)	34 48 24.7	95 54 41.4	
McAAP Station (@ McAAP Gate)	34 50 23	95 50 19	

Seismic Stations

	N Latitude	W Longitude
East Seismic Station	34 34 39.5	095 52 01.3
North Seismic Station	34 52 53.0	095 54 45.8
South Seismic Station	34 45 44.9	095 57 24.4

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Appendix C: Comparison of Acoustic Data from MCAAP and SNL

As a routine procedure, the MCAAP demolition range operating personnel monitor noise levels at three acoustic monitoring stations. Since measurements at these stations are recorded only when signals exceed a variable minimum threshold, continuous data was recorded only at the closest station (MCAAP) located at the MCAAP gate. The spatial relationship of the MCAAP acoustic station and the SNL East acoustic station is shown in Figure C-1, and the comparison of data from the two stations is given in Figures C-2 and C-3.

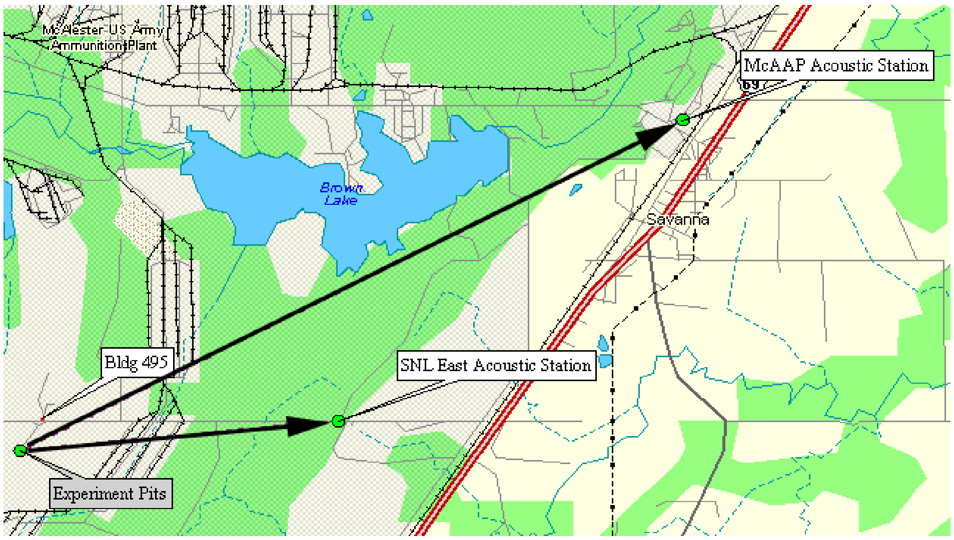

Figure C-1. Spatial Relationship of MCAAP and SNL-East Acoustic Station

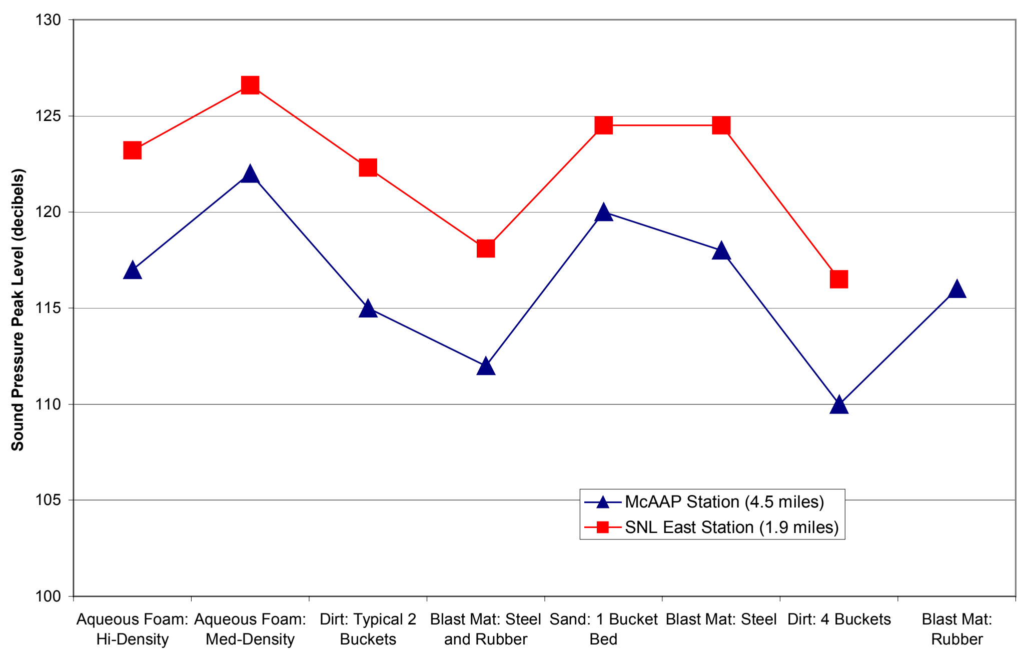

Figure C-2. Comparison of MCAAP and SNL Acoustic Data for 7/15/00

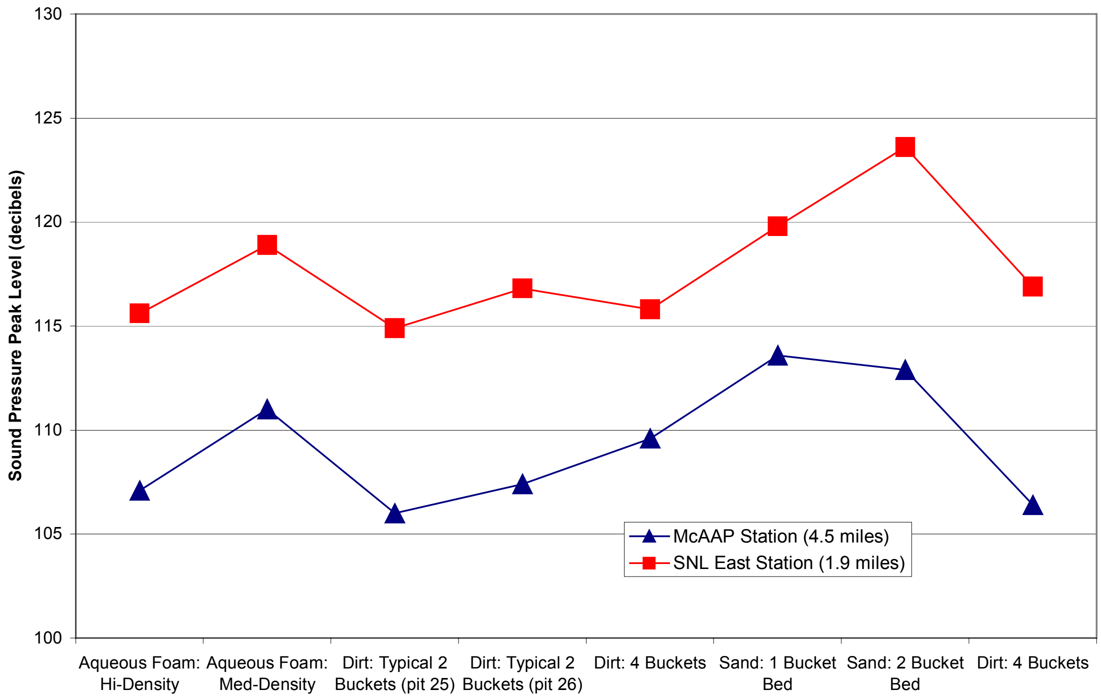

Figure C-3. Comparison of MCAAP and SNL Acoustic Data for 7/17/00

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