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Rigid Polyurethane Foam (RPF) Technology for Countermine (Sea) Program – Phase 1

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Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
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Rigid Polyurethane Foam (RPF) Technology for Countermine (Sea) Program Phase 1

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Abstract

This Phase 1 report documents the results of one of the subtasks that was initiated under the joint Department of Energy (DOE)/Department of Defense (DoD) Memorandum of Understanding (MOU) for Countermine Warfare. The development of a foam that can neutralize mines and barriers and allow the safe passage of amphibious landing craft and vehicles was the objective of this subtask of the Sea Mine Countermeasues Technology program. This phase of the program concentrated on laboratory characterization of foam properties and field experiments with prefabricated foam blocks to determine the capability of RPF to adequately carry military traffic. It also established the flammability characteristics of the material under simulated operational conditions, extended the understanding of explosive cavity formation in RPF to include surface explosions, established the tolerance to typical military fluids, and the response to bullet impact. Many of the basic analyses required to establish the operational concept are reported. The initial field experiments were conducted at the Energetic Materials Research and Testing Center (EMRTC) of the New Mexico Institute of Mining and Technology, Socorro, NM in November 1995 through February 1996.

Acknowledgement

The Project Manager wishes to recognize the contributions of the following Sandia staff members: C. T. Coffin, Technical Support; P. B. Rand and B. G. Hance, Chemical Characterization; R. J. Kipp, Analysis and Scale Model Experiments; W. K. Tucker and J. T. Hitchcock, MOU Funding; R. T. Shibata, Contract Management; and D. L. Noel, Technical Writing. Los Alamos Technical Associates, Inc. provided Test Planning, Field Experimentation, and Documentation.

The contributions and services performed by the Staff of New Mexico Tech - EMRTC are especially appreciated: Dr. Van Romero, Director; Dave Colis, Assistant Director; Steve Welch, Project Engineer; Dennis Hunter, Safety; Daryl Cases and Scott Crespin, Field Technical Support; Larry Kennedy and Chris Jones, Explosive Ordnance Experiments; Jim Peralta and Eddie Savedra, Flammability Experiments; and Bill Shell and Paul Romero, Photography and Video. Additionally, Dr. Gordon McKeen of the New Mexico Engineering Research Institute assisted by his advice and the loan of a traffic counter and conical penetrometer.

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EXECUTIVE SUMMARY

Amphibious assaults for forced entry power projection "From the Sea" often encounter anti-invasion barriers seeded with shallow water sea mines, anti-tank mines, and anti-personnel mines. This mined barrier network usually extends from the surf zone up the beach to about the high water mark. This dangerous area must be crossed "in stride," by both men and vehicles, while minimizing the exposure of assault troops to covering fires from overwatching forces.

Sandia National Laboratories has completed the first phase of exploration of the use of rigid polyurethane foam (RPF) as a passive method to neutralize mined barriers. The RPF material being considered for this application is stored and shipped as a two-part liquid which, after mechanical mixing, expands to up to 60 times its original volume depending on the strength required in the finished foam. This characteristic allows it to be transported with minimum bulk (cube) in a displacement hull such as in a ship's tanks. Although the gross weight is the same, only a small fraction of the volume required for an assault need be transported. The material can be moved by normal pumps, piping, and hoses to the delivery point where it is mixed and expands to provide the required volume. RPF materials can be formulated to expand well in water and to set up in minutes forming a lightweight but durable surface. Under normal conditions of use and/or deployment, Rigid Foam is not expected to produce a significant health hazard. (See Appendix B).

This RPF technology is one project of the Countermine (Sea) Program initiated by the DOE/DoD Memorandum of Understanding (MOU). Although RPF technology is not mature at the present time, Sandia has significant experience with the use of foam in a variety of applications, including structural/mechanical components for weapons, insulation of high risk transportation systems, and non-lethal applications for security systems. A Technology Coordination Group (TCG) with representatives from interested DoD agencies was organized and the MOU provided funding to Sandia to explore the potential of RPF as a counter to sea mines and barriers. Once the technical feasibility of using RPF material in this application is proven, the DoD will need to contract with industry to develop an operational assault system; Sandia can assist with transfer of the technology, as needed.

Sandia has envisioned the on-site production and deployment of RPF into a ramp-type shape that would be emplaced over the mined barriers in the assault lanes of an amphibious operation. The basic task was to determine if RPF was capable of withstanding the safe passage of amphibious vehicles and affording protection against detonation of mines in an anti-invasion barrier and whether it could be operationally developed. The initial tasks in this first phase of the project were to determine by laboratory and field experiments the feasibility of producing and employing foam that would endure the hostile environments of a combat scenario. A series of laboratory experiments were conducted in Sandia's chemical laboratory facilities. Because the fundamental issue was to prove the feasibility prior to proceeding to more technical experimentation, prefabricated blocks of varying densities were obtained from Allied Signal, Kansas City, MO. Field experiments were performed between November 1995 and February 1996 at the Energetic Materials Research and Testing Center (EMRTC) of the New Mexico Institute of Mining and Technology, Socorro, NM. EMRTC has an internationally renowned explosive testing experience with military requirements and equipment.

Experimental work to test the suitability of using RPF in combat situations was divided into five categories: Chemical Laboratory work to verify basic foam characteristics; Operational Experiments to investigate the ability to withstand simulated battlefield conditions; Delivery Technique Exploration to identify engineering direction and problems; Analytical work to provide a firm basis for experimentation; and Demonstrations to prove the concept to the military users. The Navy may fund the final demonstration as part of its Countermine Warfare Advanced Concept Technology Demonstration (ACTD) in FY99. The effort during Phase 1 has been concentrated on lab work, operational experimentation, and those analyses required to support these two areas and operational deployment.

Laboratory work has been conducted by Sandia's Materials and Process Sciences Center/Department 1811. A variety of commercially available foams was initially tested for their ability to rise and produce good quality, hard foam in water. Those that proved best were further tested to determine their mechanical strength under different operational conditions. Experiments to determine mechanical strength vs foam density, foam temperature, and time were conducted. Another series of lab experiments investigated the effects of varying component temperature, water temperature, and mix precision on the foam strength. Experiments were conducted on both standard and intumescent foams. A series of experiments were conducted to optimize the ability of layered foam to adhere to itself without leaving "cold joints".

The laboratory experiments show that some commercially available RPF products provide good foam of the required densities under a reasonable range of simulated operational conditions. These materials are capable of expanding 20 to 60 times in volume from liquid to solid state in a matter of a few minutes, regardless of most environmental variations.

Data developed during the lab testing indicate that some RPF products are eminently suitable for use in an operational water/beach environment. One particular product, North Carolina Foam Industries (NCFI) type 811-91, was judged to fulfill these specific requirements best. Specific development of an optimized foam mix was considered premature at this stage. The NCFI 811-91 was judged to have adequate performance characteristics to determine the feasibility of using RPF in this application.

Operational experiments were conducted using 2, 4, and 6 pound per cubic foot (pcf) standard RPF foam blocks prefabricated by Allied Signal. These blocks were poured using available foam, BKC 44307, and have some properties less ideal for this application than the NCFI 811-91. This material was chosen as having representative properties and was available in time to support field experiments concurrent with the lab work.

Two areas were of particular interest to the TCG due to their operational impact: the reaction of the cured foam to fire and the ability of foam to carry amphibious assault vehicles (AAV-7) and landing craft air cushion (LCAC) traffic.

Flammability experiments were conducted in two series using both 2 and 4 pcf foam. In no instance did the foam develop a flash fire. It tended to burn very much like light wood. The foam used for these experiments contained no fire retardant component. The foam chosen for future experiments may have a moderate level of retardant additive. In these experiments, the foam showed a regular tendency to self extinguish, once the initiating heat was removed.

Trafficability experiments were conducted using 2, 4, and 6 pcf foam in 54-inch cubes. The blocks were traversed at both low and moderate speeds (~15 mph) using an M110 8-inch self-propelled howitzer weighing 27 tons and an M60 main battle tank at 53 tons to represent tracked amphibious vehicles. A light truck at 3.5 tons and a 6 x 6 cargo truck at 12 tons were used to represent wheeled vehicles. The tracked vehicles were run both with and without their rubber road pads. The experiments were designed to ensure the loading simulated operational conditions.

The RPF foam blocks carried vehicle traffic to a level well beyond that necessary to satisfy the initial objectives.

- The 2 pcf foam developed a 12-inch rut after 8 to 12 passes by a tracked vehicle and was judged usable, but somewhat marginal for this application.

- The 4 pcf foam carried between 36 and 163 passes before developing a 12-inch rut. The M110 howitzer at moderate speed and without pads eroded the foam worst. Both the M60 and the M110 with pads and moving slowly could make more than 150 passes. The 6 x 6 truck at 20 mph made 96 passes.

- The M60 produced only 1/2 inch impressions in very limited experiments with 6 pcf foam. The 6 x 6 truck could make 167 passes at 20 mph before developing a 12-inch rut in the 6 pcf foam.

- Erosion of the foam block surface increased with higher speed traffic and with bare, more aggressive tread design. Erosion decreased with lower speed and with road pads installed.

- RPF in 2 pcf density is marginal for an assault ramp, if tracked vehicles are to be used on it. Four pcf foam is more than adequate to withstand the traffic of the anticipated number of AAV and LCAC passages. If the assault conditions dictate the use of LCACs only, even 1 pcf foam should prove adequate. Foam density will be optimized later in the project but is expected to be adequate in the 2 1/2 to 3 1/2 pcf range for tracked vehicles.

The results of the trafficability experiments show that moderate density RPF foams are quite capable of carrying the traffic of the first few days of an amphibious assault.

In addition to trafficability and flammability, other experiments involved small arms and cannon caliber projectile impact, explosive cavity formation, POL product compatibility, and roadway repair capabilities.

Rifle caliber small arms were tested in 2 pcf foam and projectiles were found to slow down and tumble without causing any considerable damage. Cannon caliber (30 mm), high explosive/point detonating fuzed projectiles were shown to perforate 2 pcf foam without detonation, but did detonate in 4 pcf foam, causing moderate damage. Explosive experiments using 10, 100 and 1,000 gm charges in both 2 and 4 pcf foam resulted in cavities which were accurately predicted by previously published Sandia data. The cavities formed by moderate-sized ordnance in a large poured foam ramp should be repairable. POL products: lubricating oil, turbine fuel, and coolant specified for the AAV-7 and LCAC were used in an experiment with 2 and 4 pcf foam. After several months, there was no discernible degradation in the foam samples. Roadway repair experiments using 6 pcf foam have begun.

The use of RPF materials in this application is still an immature technology. Considerable work remains to be done to prove the concept is viable and to engineer an operational system. These experiments have established that rigid foams are capable of covering over a mined barrier, absorbing at least a portion of ordnance detonations, and providing a usable roadway for assault vehicles without introducing new hazards or presenting incompatibilities with other operational equipment. Further analyses and experimentation are scheduled for FY97-98 to investigate other RPF characteristics to demonstrate the feasibility of this concept.

Nomenclature

AAV	Amphibious Assault Vehicle
AAAV	Advanced Amphibious Assault Vehicle
ACTD	Advanced Concept Technology Demonstration
AFB	Air Force Base
AP	Armor Piercing
AP-I	Armor Piercing - Incendiary
cal	caliber
cm	centimeter
DoD	Department of Defense
DOE	Department of Energy
EMRTC	Energetic Materials Research and Testing Center
ft	foot
ft/lb	foot/pound
ft/s	feet per second
FY	Fiscal Year
GAU	Gun Assembly Unit
gm	gram
gr	grain
HE-I	High Explosive - Incendiary
lb	pound
LCAC	Landing Craft Air Cushion
min	minute
mm	millimeter
MOU	Memorandum of Understanding
mph	miles per hour
ms	millisecond
NATO	North Atlantic Treaty Organization
NCFI	North Carolina Foam Industries
NEPA	National Environmental Policy Act
NTS	Nevada Test Site
O.D.	Outside Diameter
oz	ounce
pcf	pounds per cubic foot
POL	Petroleum Oil Lubricants
psi	pounds per square inch
QA	Quality Assurance
RPF	Rigid Polyurethane Foam
TBD	To Be Determined
TCG	Technology Coordination Group
USMC	United States Marine Corps
UV	Ultraviolet
WBS	Work Breakdown Structure

SECTION 1

Background

Sandia National Laboratories is currently investigating the application of existing and emerging technologies to develop countermeasures to sea mines and to enable the neutralization of the barriers commonly used to defend beaches against amphibious assault. This project is one of several being sponsored jointly by the DOE and the DoD.

One of the technologies under investigation for barrier crossing involves the use of massive quantities of RPF foam to form ramps or temporary piers. A major part of that investigation is determining the foam properties required to adequately carry the traffic of military vehicles both during an assault and in the following days.

At present, there is no acceptable way to neutralize surf zone obstacles (mined or passive) during an amphibious landing that does not entail very high risk to personnel and to the success of the operation itself. It is currently necessary to send Special Forces swimmers into the surf zone a few hours before the assault to attempt to neutralize most of the mines and barriers. Unfortunately, most of the larger mines and barriers use anti-personnel mines to prevent such activity. Both Navy and Marine Corps commands have indicated that one of their strongest needs is in this area and have encouraged us to place this project highest on our list of technologies proposed for development under the MOU program.

Historically, amphibious assaults have often encountered wide areas of sand or mud that contain mines of several types as well as anti-invasion barriers. Our initial work indicates great promise for using this foam technology to defeat these defenses. In addition, the Marine Corps Combat Engineer Officers on the project advisory group have proposed several other applications, such as facilitating the crossing of ditches and tank traps.

One of the major anticipated military advantages of these foam materials in combat and mobility situations is that it is necessary to transport only a small portion of the volume of material required for any application because of the expansion of the foam as it rises. Expansion ratios lie in the range of 1:16 to 1:60.

Recent news reports have also illustrated the need for an application that could assist in dealing with extreme mud, such as that encountered in the approaches to the floating bridges constructed during the winter of 1995 in Bosnia or the extensive mud flats such as those encountered during the Inchon landing in Korea in September 1950.

Sandia has conducted a series of preliminary experiments on prefabricated foam blocks of different densities to assess the traffic carrying abilities of this material, its flammability, and its tolerance to explosives. Prefabricated blocks were used to enable us to learn more about these different aspects of this material before developing the dispensers necessary for advanced experiments and operational use on water. Commercial dispensers are readily available to be used in the next phase of experiments and could be adapted for less demanding applications such as mud control; work on operational dispenser development has begun.

SECTION 2

General

Foams that Neutralize Mines and Barriers: There are several issues of significance that are derived from an operational perspective and these serve to guide the initial attempts to develop the foams for this application. These issues are:

- Sufficient quantities of appropriate foam must be emplaced under hostile conditions without access to the beach to form a ramp over the mines and obstacles with minimum exposure of troops to hostile fire.
- The foam must form a ramp sufficiently uniform and sturdy to permit several LCACs and/or tracked vehicles to pass over it sequentially.
- The foam must cure in a short and predictable length of time under widely different environmental conditions of temperature and humidity. It must also withstand the effects of some, yet to be determined, surf action for a period of time sufficient to permit passage of several LCACs and vehicles.
- The ramp should not be rendered impassable by the explosion of a mine embedded in the foam and it should provide a measure of safety to those LCACs and vehicles crossing it.
- The foam should spread the load of crossing vehicles sufficiently to reduce their pressure signature below what is required for pressure mine detonation and, if possible, should provide a magnetic and acoustical shield to inhibit mines from firing on those signatures of the vehicle.
- The foam and its deployment system must not be prohibitively expensive nor exceedingly complex. Nor should its constituents be difficult to obtain.
- The foam should not be overly damaging to the local environment and a removal method that is not exceedingly difficult or expensive must be found.
- Foams developed for Mine and Barrier Neutralization may have civilian applications in relief of natural disasters, such as stabilizing buildings or bridges damaged by earthquakes, or constructing emergency bridges in swampy areas during floods. Installed on ships, foam generators of the type envisioned here could prevent loss due to hull puncture or cargo shifting in heavy weather. Foam generators could also mitigate cargo spills by remote controlled temporary patching. Temporary roads could be constructed over difficult terrain such as permafrost or swamps for oil exploration purposes.

Phase 1 Reporting:

Phase 1 of the project was limited to experiments that could be accomplished using prefabricated foam blocks. It was considered that the purchase of an expensive foam dispenser could not be justified until RPF was demonstrated to be a reasonable solution to the shallow water mine problem. The analyses needed to scale the experiments, establish capabilities, and verify basic assumptions were all accomplished by Sandia's Exploratory Sensors and Munitions Department (2522). Chemical laboratory characterization of the properties and adaptability of RPF were done by Sandia's Organic Materials Synthesis/Degradation Deptartment (1811).

Work Breakdown Structure:

For program management ease, the required task elements were divided and subdivided into a Work Breakdown Structure (WBS) that shows subtasks to five levels. This system allows task prioritization based on time and funding constraints while maintaining the overall project goals. The WBS, updated as necessary, will be used as the basic roadmap for the entire project.

The task elements included in this WBS, at present, are only those required to produce a reasonable assurance that a mine/barrier system can be defeated using foam technology. A much larger WBS array will be required to cover engineering and test of the logistic and delivery portions of the system. The WBS produced for this Countermine Foam Feasibility Study is shown as Figure 1. Completed items reported in this document are indicated by a slash through the box.

The WBS will be used throughout the program and will change as more understanding is gained. As activities and experiments are completed and reported, they will be crossed off as illustrated in blocks 1.1.1.1.1, 1.1.1.1.2, and several others in Figure 1. Figure 1 also divides of the experimental work into five categories based on the type of work required: laboratory experiment; field experiment; combined lab and field experiment; analyses; and demonstrations.

Those items in the WBS that will require pouring foam in the field (yellow border) will begin in late FY96 or early FY97.

During the life of this project it is expected that several more phased reports will be written. The intent is to follow the WBS structure in each report. The current WBS chart will be annotated to show which phase report recorded the experimental results for each completed WBS block.

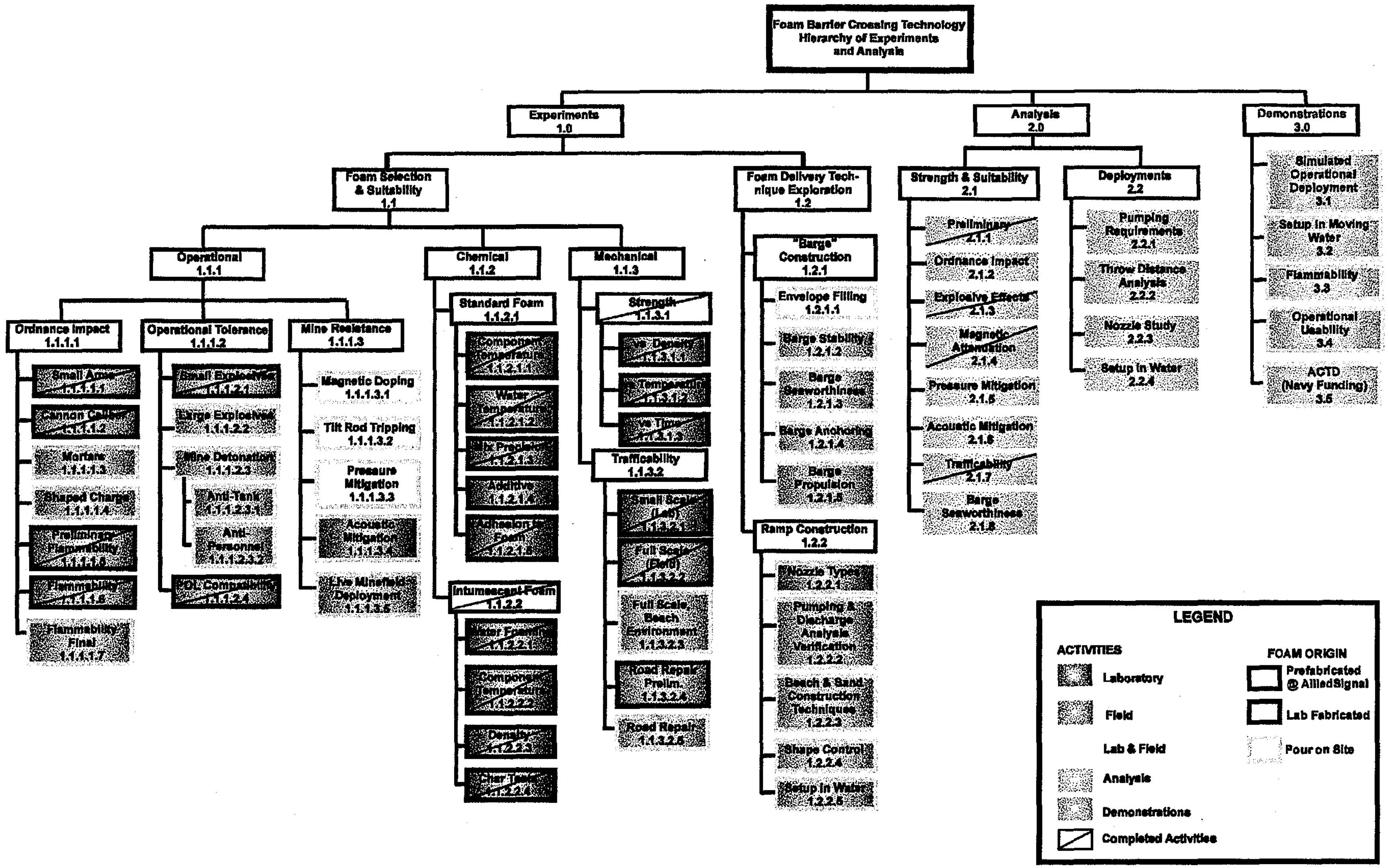

Figure 1. Work Breakdown Structure (as of Feb 96)

Foam: The projected experiments are further divided by the source of the foam being tested. Prefabricated 2, 4, and 6 pcf blocks were provided by Allied Signal, Kansas City, MO, under contract to Sandia. This was done to avoid spending $50,000 to $100,000 of project funds before it was possible to properly evaluate the foam dispenser requirements. Allied Signal has a medium size dispenser, bought for different uses, but was able to form and ship the required 54-inch cube foam blocks. The laboratory-fabricated blocks are smaller (~1 ft^3), formed using a very small foam dispenser in Sandia's Chemistry Lab. These small samples were used only for the chemical laboratory work to define the material characteristics of the foam. The experiments noted as "pour on site" will require buying a fairly large foam dispenser or several medium size dispensers. Specifications for this equipment were released in February 1996 and the machinery is expected on-site in the summer of 1996. The specifications are in Appendix A.

Test Site Selection: In August and September 1995, R. L. Woodfin contacted personnel in the Sandia's Engineering Support Center (Department 2700), New Mexico Tech - EMRTC, the Nevada Test Site (NTS), and the Tonopah Test Range regarding their ability to provide a site for countermine foam experiments. A draft test plan and an experiment requirements package were generated and forwarded to Sandia 2700 and EMRTC for bids. Both NTS and the Tonopah organization decided not to bid because of environmental (NEPA) concerns. Sandia 2700 was undergoing a major downsizing and reorganization at the time and could not commit to testing before Spring 1996. New Mexico Tech - EMRTC submitted a cost-effective bid for the foam experiments and had no problems with NEPA issues nor with gearing up for an immediate start. Several meetings with EMRTC showed their organization to be responsible, cost conscious, and enthusiastic. EMRTC was placed under contract to provide the range areas, ordnance expertise, field engineering, and a large portion of the labor involved. In addition to providing expertise, ranges, and labor, EMRTC has immediate access to M60 main battle tanks and M110 self-propelled 8-inch howitzers. There are a variety of military trucks left over from previous test programs and a reasonable selection of explosives, projectiles, and mines in EMRTC's inventory.

Phase 1 Experiments: (Those done before foam dispenser acquisition)

During the initial planning of the program, two areas concerned members of the DoD TCG: Trafficability and Flammability. Questions concerning these areas needed to be answered rapidly and, in the affirmative, to have a viable program. Other issues were added to Phase 1 to get the optimum fit considering project cash flow and the highest probability for best results per test day. Seven field experiments identified in the WBS, including six in the Operational area (1.1.1) and one in the Trafficability area (1.1.3.2), have been completed and are reported here.

Lab tests have been completed on seven experiments on standard foam and all four on intumescent foam. Both lab and full-scale field experiments on trafficability have also been accomplished. A series of analyses on strength/suitability and deployment were performed.

The results of these experiments and analyses constitute Sections 3 through 6 of this report. Sections 3 and 4 will document the work accomplished in Phase 1 in WBS numerical order.

EMRTC Test Area: New Mexico Institute of Mining and Technology (New Mexico Tech) is located in the city of Socorro, 80 miles south of Albuquerque. EMRTC is an autonomous division of New Mexico Tech and operates a 34 square mile test area immediately west of the main campus. For the experiments conducted from November 1995 through February 1996, four range areas were used: the Main Pad area for foam trafficability, the West Valley Flag area for explosive experiments, the 1000 meter West gun range for cannon caliber impacts, and the Fast Cook Off Site for flammability experiments. Figure 2 shows the physical layout of the ranges.

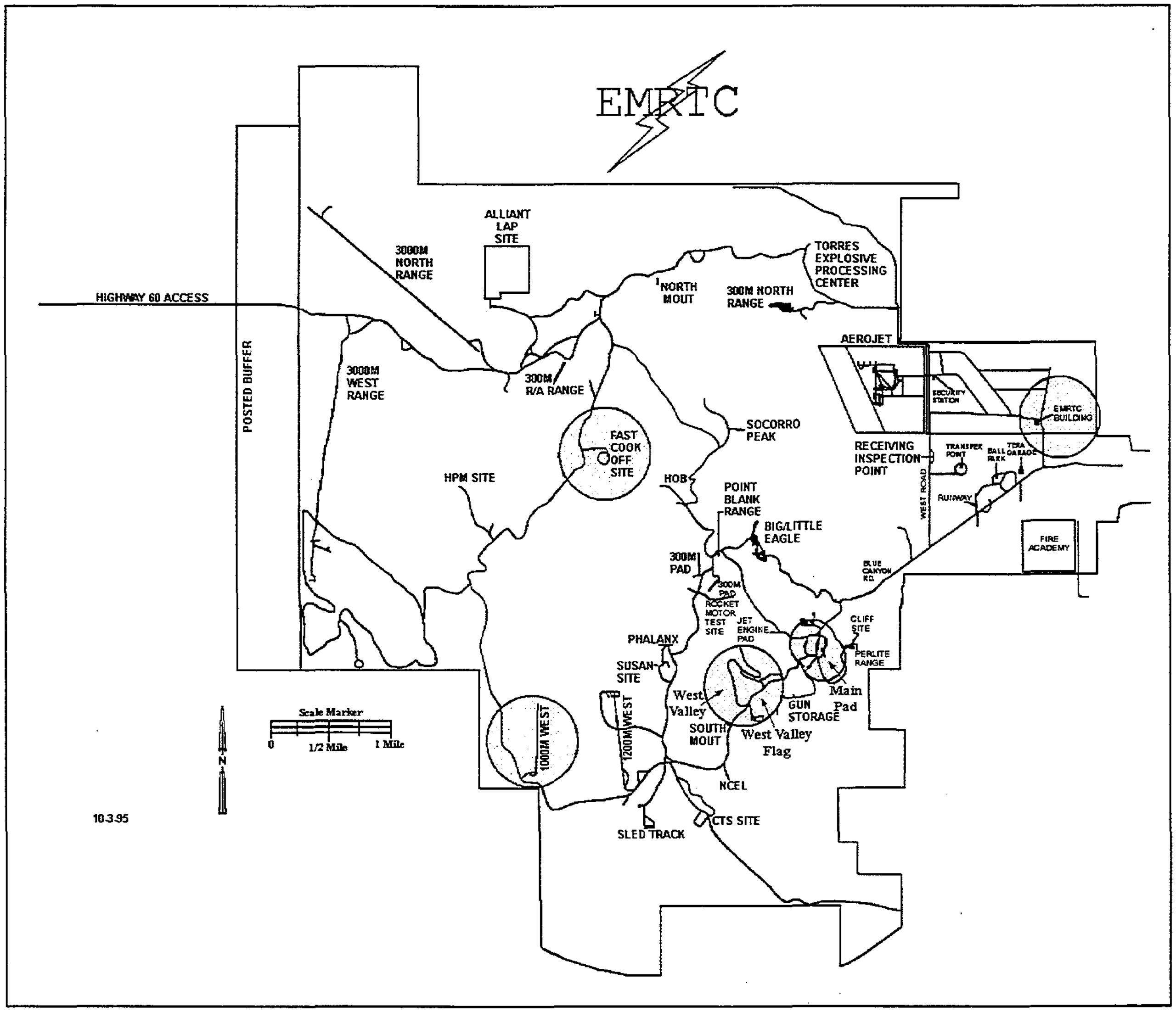

Figure 2. Map of EMRTC

SECTION 3

Foam Selection And Suitability Experiments

Operational Suitability 1.1.1

Ordnance Impact 1.1.1.1

Small Arms 1.1.1.1.1

Introduction: (The presentations of these experiments are in the order of the WBS. This order is not related to the importance of the experiment nor the effort expended.)

In this series of experiments, we attempted to show the effect small arms ordnance would have on the foam when shot from distances of about 100 meters. In so doing, we wanted to determine how well the foam would survive a shot and whether any tumbling of the ordnance would occur on its path through the foam block.

By doing these experiments, we wanted to determine whether the foam could withstand small arms ordnance without its structure being blown completely apart. The small arms used included a Colt M-16 HB and a Winchester M700. Single rounds were successfully fired through 2 pcf foam blocks, producing clean entry holes and slightly elongated exit holes, indicating that tumbling had taken place inside the blocks.

Result: The complete perforation of 2 pcf foam with no structural damage indicated that small arms will not destroy a foam ramp.

Conclusions:

Rifle caliber small arms will not cause great amounts of damage to a foam ramp.

Two pcf foam lacks the density to provide any protection from rifle caliber small arms.

Task Order* :

Use firing range at about 100 meters. Begin with 7.62 mm ball and armor piercing (AP) (AP-incendiary if available). One round of each will be adequate. Later, fire one round 50 cal AP-I. Use ~10 ft foam path for 30 cal & 20 ft for 50 cal. Try to minimize foam use by having impact point about 1 ft from edge of block. Use witness plate at exit to check for tumbling. If equipment readily available, measure entering and exiting velocities. Use 2 pcf foam first; I will decide after seeing results whether to also use 4 pcf foam for repeat experiments.

Actual Experiments:

Target: Foam blocks of 2 pcf measuring 7.5 inches W x 15 inches H x 12 ft 10.5 inches L, in three pieces; were taped together, end butted along a steel U channel stiffener. Figure 3 shows the target blocks, numbered 02 through 04 from front to back, weighted with rocks from the site.

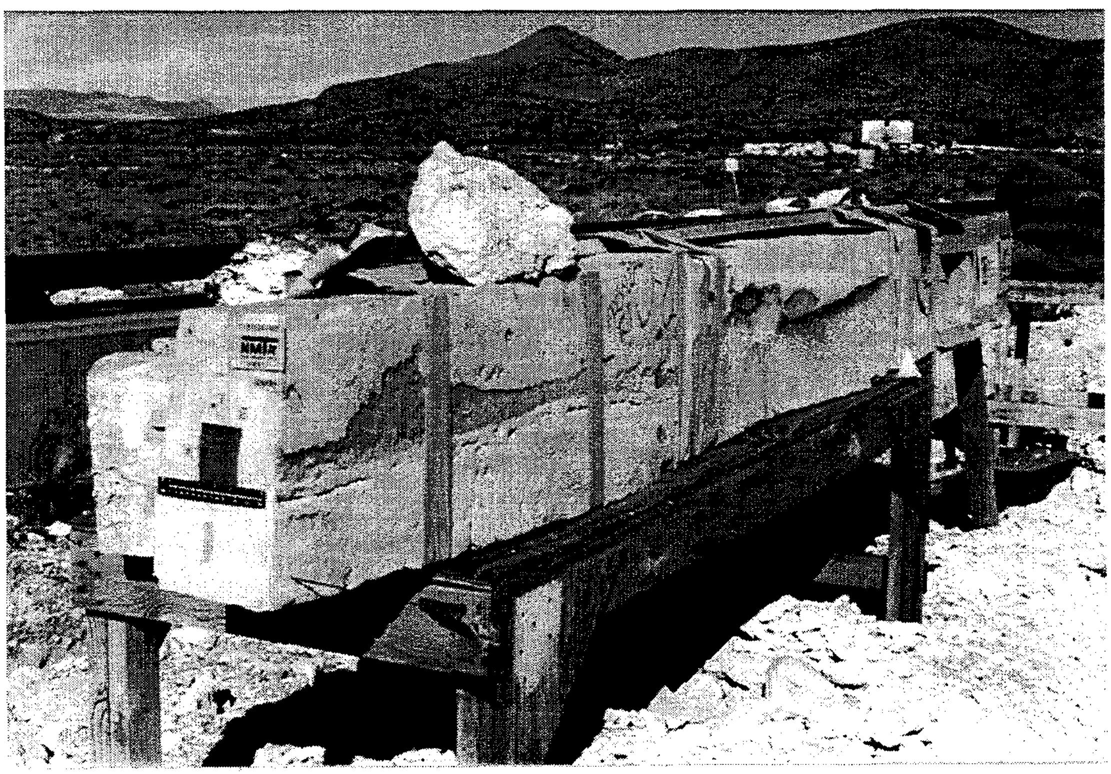

Figure 3. Target Blocks

Range: 110.85 meters - muzzle to front of first block.

* The Task Order text retains its rather terse terminology used in the test plan. This was always supplemented by discussions and verbal test planning. The actual experiment, therefore, varied somewhat from the Task Order.

Small arms: M-16 HB (Civilian/Colt): 5.56 x 45 mm NATO/55 gr ball
Winchester M700: 7.62 x 51 mm NATO/145 gr ball (from M-60 linked belt)

Procedure: Single rounds fired electrically from 110 meters, lengthwise through the three foam blocks into a sandbag backstop. Doppler radar tracking on projectile to impact. Figures 4 and 5 show two of the three radar plots of time vs velocity. Entry and exit holes marked. Four rounds fired: two 5.56 and two 7.62.

Results: All four rounds perforated the entire 12+ ft of foam and embedded in the first layer of sandbags. Entry holes showed no tumbling; all four exit holes were elongated - indicating tumbling. None of the projectiles penetrated the first sandbag layer. Three projectiles recovered: one 5.56 projectile showed little deformation except at tip, one side skinned, probably by sand. Both 7.62 projectiles were flattened out of round on long axis and skinned by sand; one showed base deformation with what may be white rock powder and sandbag fabric stuck to one side.

Posttest Inspection: Sectioned 5.56 mm channel nearest the top of the forward block. Bullet began to tumble at about 77 cm from entry point and continued tumbling through all three blocks. Cavity is about 28.5 mm in diameter in rear half of first block and through blocks 03 and 04. Figures 6 and 7 show the exit holes and the projectile channel in block 02.

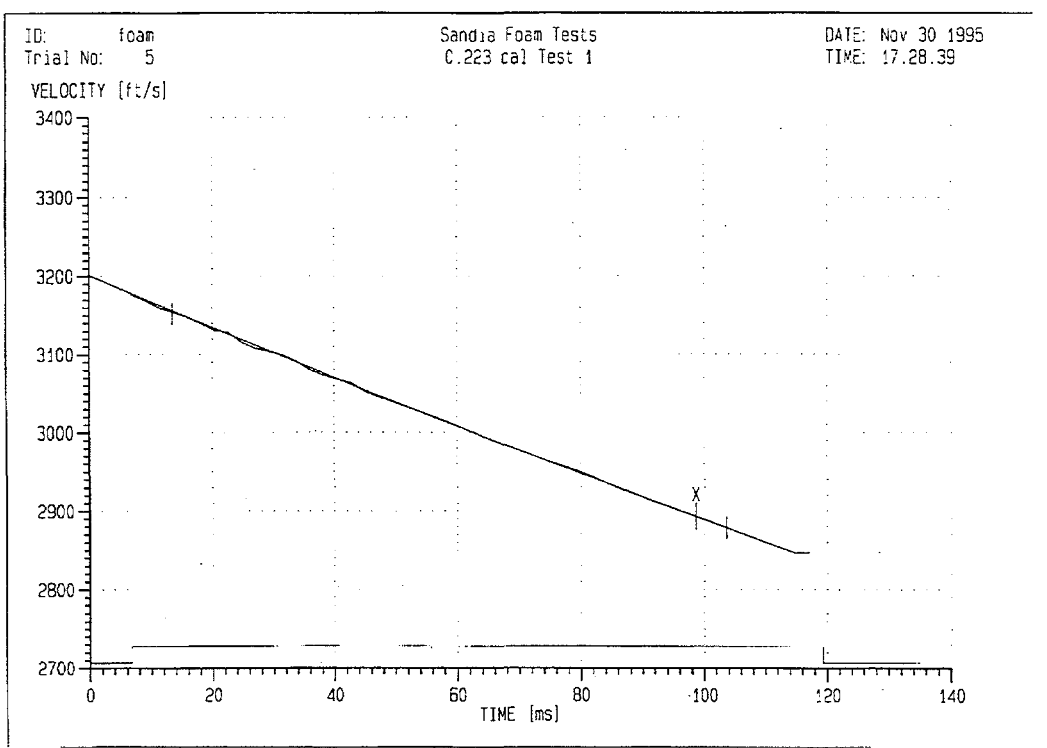

Figure 4. 5.56 mm Bullet Velocity

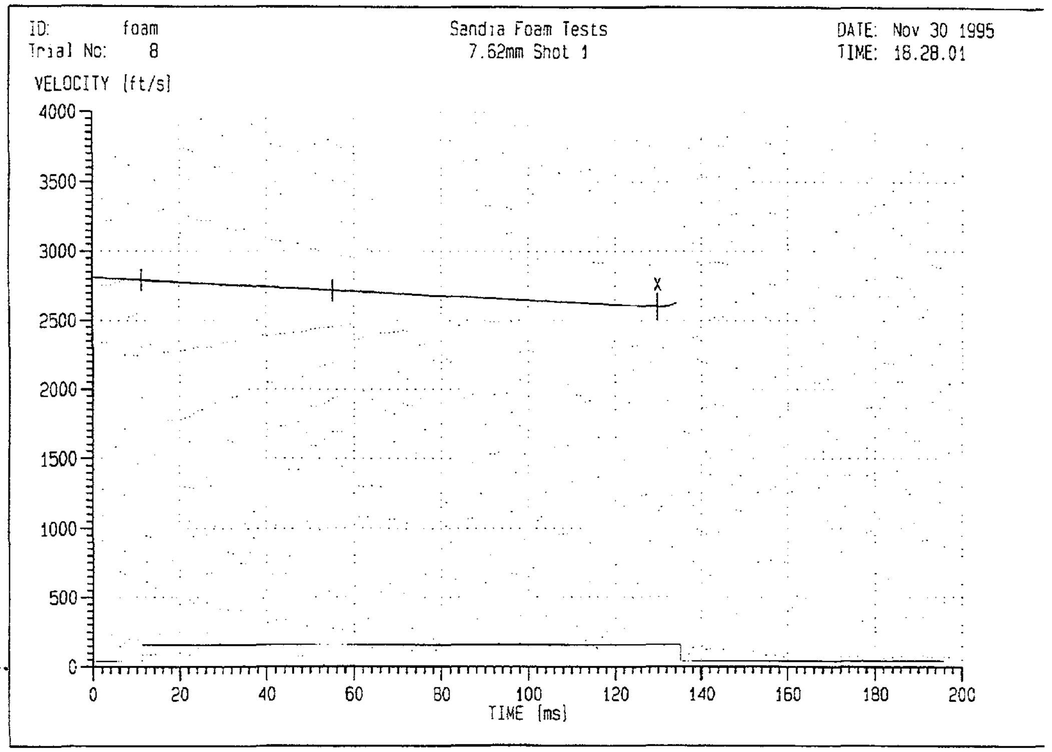

Figure 5. 7.62 mm Bullet Velocity

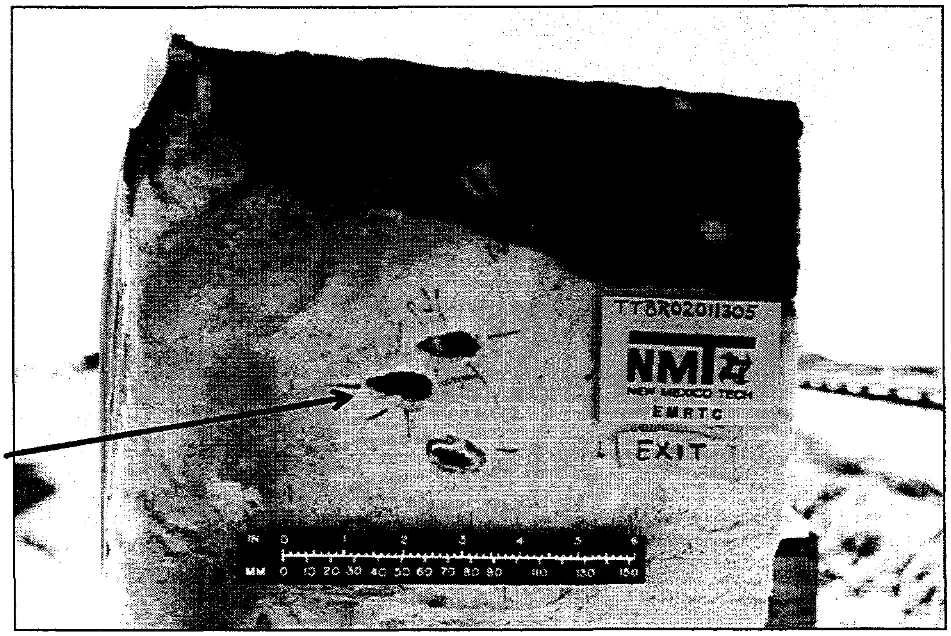

Figure 6. Projectile Exit Holes - Block #04

Note: The blocks for this experiment were constructed of pieces salvaged from the initial Trafficability and Small Explosives experiments previously conducted. The scorching visible in Figure 6 is superficial, resulting from the 10 gm Small Explosive C-4 surface shot. This illustrates the efforts made to get maximum information from the available resources.

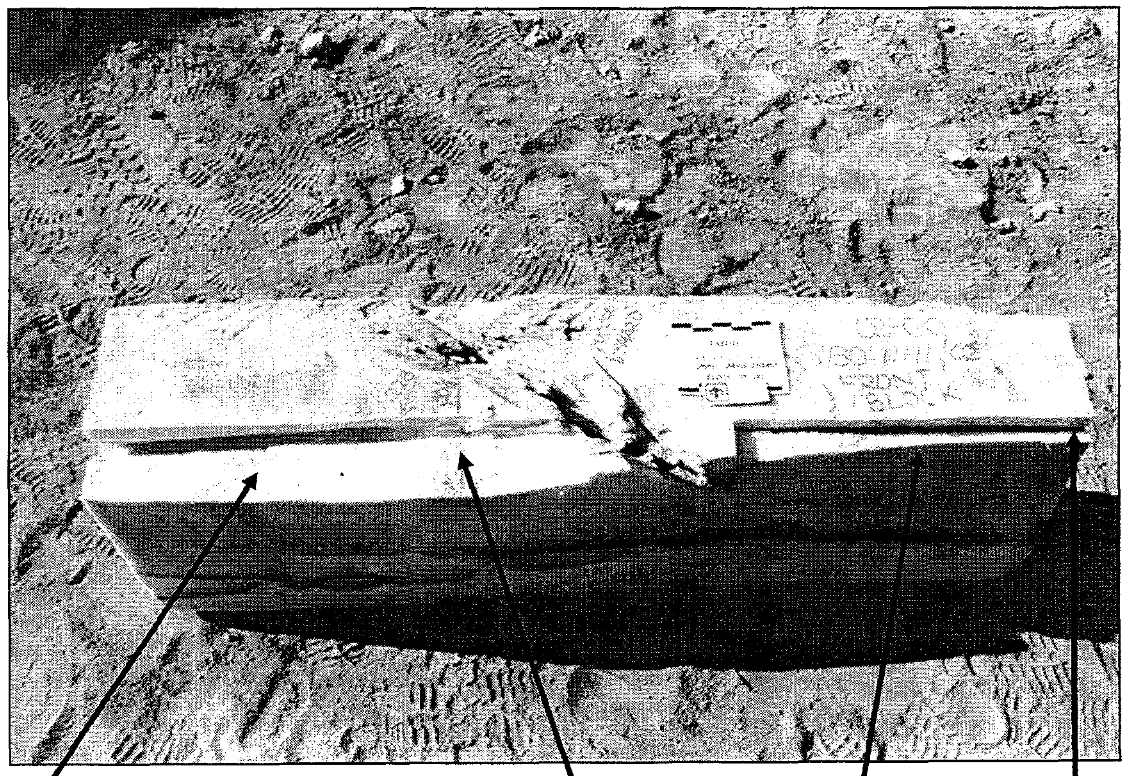

Figure 7. Projectile Channel - Block #02

Operational Suitability 1.1.1

Ordnance Impact 1.1.1.1

Cannon Caliber 1.1.1.1.2

Introduction:

In this series of experiments, we attempted to learn the effect cannon caliber ordnance would have on the foam when shot from distances of about 100 meters. In so doing, we wanted to determine how well the foam would survive a shot, whether the projectile would fuze, and whether any tumbling of the ordnance would occur on its path through the foam block.

By doing these experiments, we wanted to determine whether the foam would withstand cannon caliber ordnance without its structure being destroyed.

Results: The high explosive incendiary (HE-I) projectile did not fuze in the 2 pcf foam, but it did in the 4 pcf foam. Damage observed in the 4 pcf foam correlated well with other explosive experiments.

Conclusions:

While these two shots are inadequate to permit much generalization, they provided the initial indications needed to plan future work. Two pcf foam is probably too light to fuze most cannon projectiles. Four pcf foam will cause some sensitive point detonating fuzes to function. The cavity diameter formed in 4 pcf foam correlates well with C-4 charges embedded and detonated. Larger artillery projectiles in the 76 to 155 mm range can be expected to produce large holes in the foam, but may or may not fuze in the foam.

It was considered that destruction of the foam ramp by artillery fire was of secondary importance since a successful amphibious assault requires such batteries to be suppressed. Further investigation, using larger blocks, may be indicated later in the project.

Task Order:

Firing range as appropriate for accuracy, but ~300 to 500 meters. 1 round 30 mm HE-I. Paper witness plate for exit. Proceed as for 1.1.1.1.1.

Actual Experiments:

Experiment 1: Setup: GAU-8 30 mm gun placed 99 meters in front of 2 pcf block #02-02 with three armor safety plates about 2 meters to the rear of the block and to both sides as shown in Figure 8. One round of 30 mm PGU-13/B point detonating fuzed ammunition, HE-I was electrically fired into the block.

Results: The HE-I projectile did not fuze in the 2 pcf foam. It perforated all 54 inches of foam, exited as shown in Figure 9, and detonated on the armor backing plate.

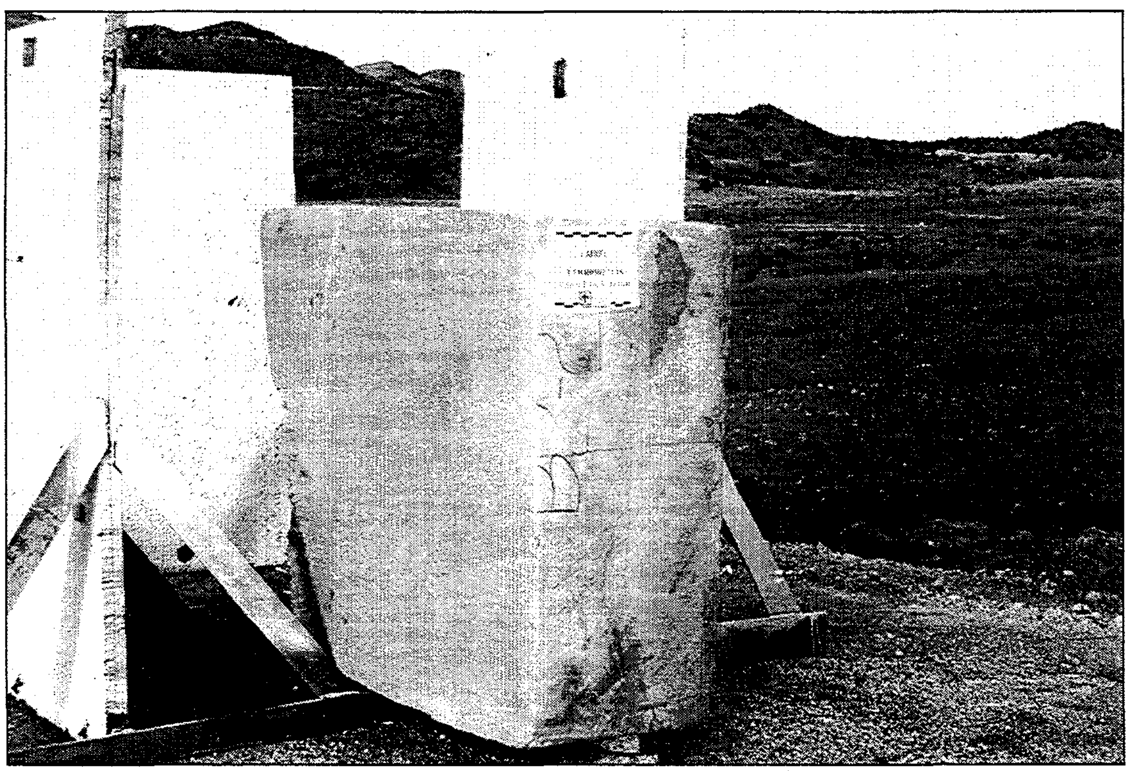

Figure 8. 30 mm HE-I Fuze Function Test Setup - Block #02-02

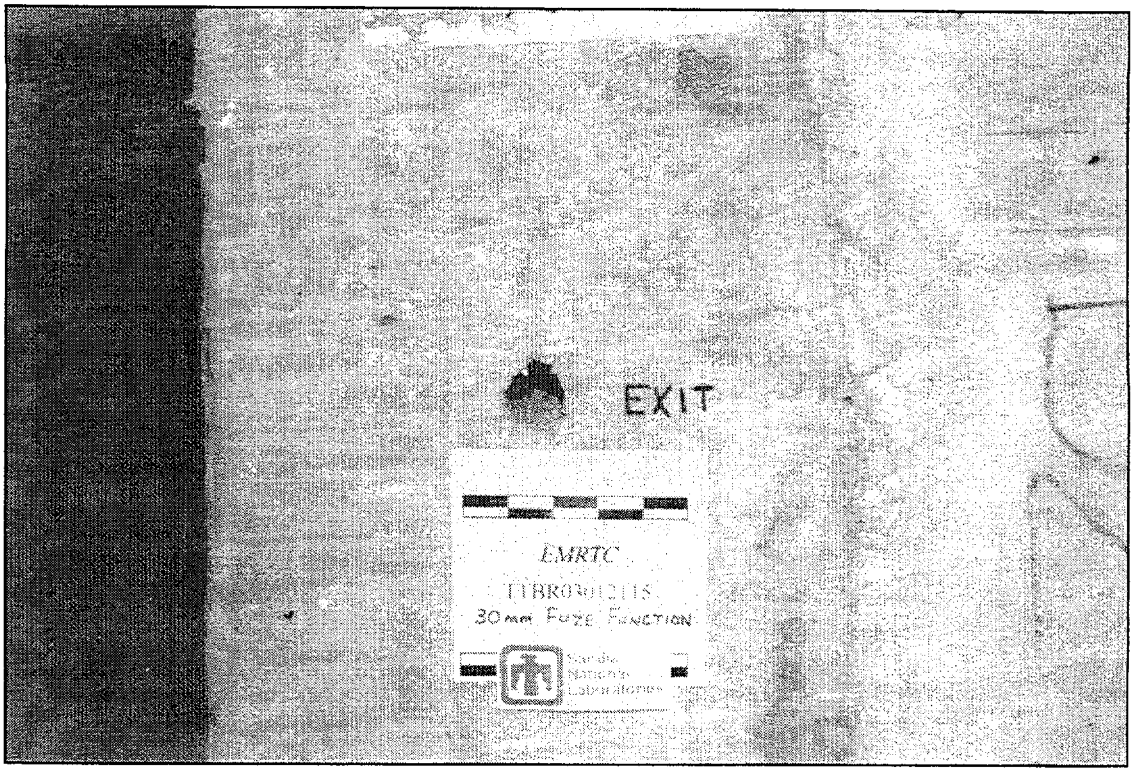

Figure 9. 30 mm Exit Hole in 2 pcf Foam

Experiment 2: Setup: Unused 4 pcf foam block # 04-05 approximately 54 x 54 x 54 inches was set up between three armor safety plates, 100 meters from the fixed site of a modified GAU-8 30 mm gun on the 1000 meter West gun range. The gun was rigged to fire electrically. The target block was oriented to present its top (skinned) aspect to the shot. Video coverage was set up to cover the front face of the target block and the rear area between the block and the rear safety plate. One round of 30 mm PGU-13/B, HE-I with quick acting, point detonating fuze M505A3 was fired top to bottom through the foam block.

Results: The 30 mm HE-I penetrated the block, detonating in the rear third of the block depth, approximately 10 to 12 inches before it would have exited. The exit cavity, shown in Figure 10, measured about 18 inches in diameter with a hole 38 inches in diameter at the rear surface of the target. Both the block fragments and remaining three-quarters of the block were peppered with projectile fragments. The cavity began at approximately 30 inches of penetration from the front face of the target, indicating fuzing after penetration of approximately 39 inches.

The block was later examined by x-ray to determine whether any fragments were trapped: very few were.

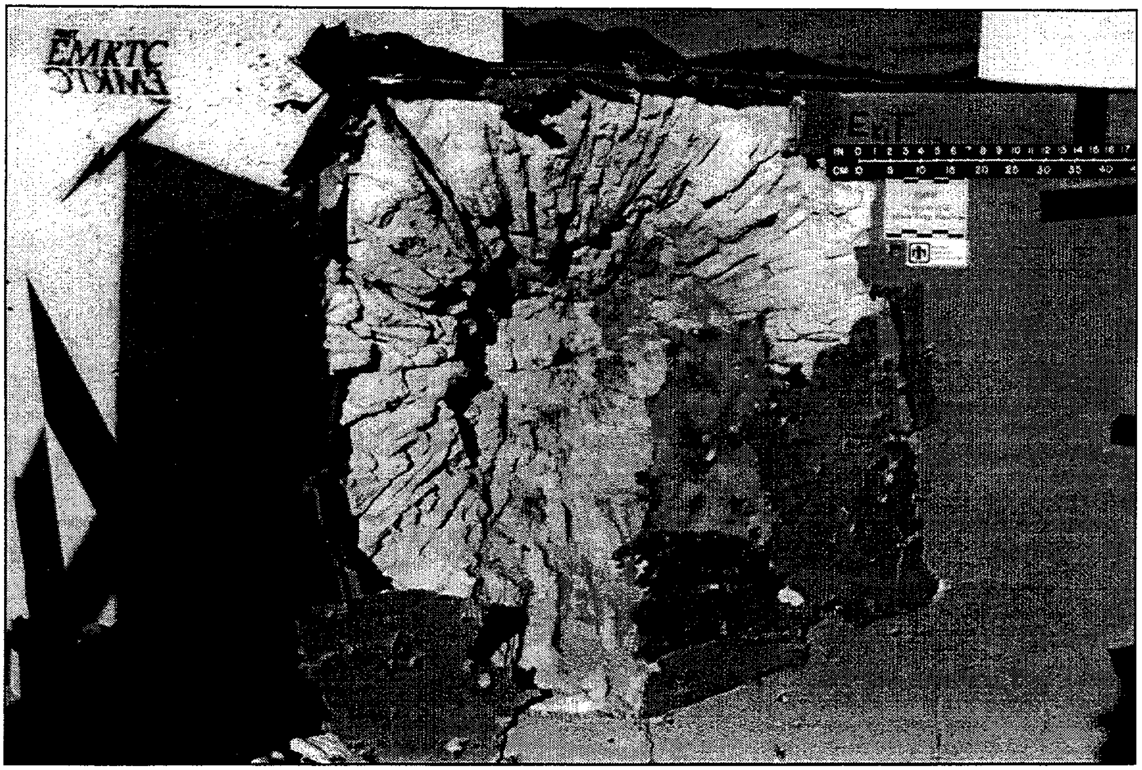

Figure 10. 30 mm Exit Cavity in 4 pcf Foam

Operational Suitability 1.1.1

Ordnance Impact 1.1.1.1

Preliminary Flammability 1.1.1.1.5

Introduction:

In the Preliminary Flammability series of experiments, we attempted to determine how well small pieces of the polyurethane foam would burn under given conditions. More specifically, we wanted to ascertain the amount of fire damage the foam would experience in various combat situations, especially fires involving fuel; however, we wanted to do this on a small scale before attempting it with a larger block of foam. Certainly, less flammable foam would standup to combat situations better.

Intumescent foams were included in this experiment to see if their fire suppressant capability would assist in preserving foam strength. These foams are formulated with chemicals that cause the outer surface to bubble up when exposed to heat. This protects the remaining portions of the foam by a combination of dead air spaces and the carbon char on the surface. It was anticipated that this ability would allow the foam to survive a fire while retaining much more of its internal strength.

By doing these experiments, we wanted to learn how rapidly the foam would burn and whether it would burn itself out with acceptable structural damage; hence, being able to withstand fuel spills, the explosion of vehicles, and the like. Small pieces of different types of foam (2 pcf standard, 2 pcf intumescent, and 4 pcf standard) were floated in aluminum pans of water with JP-8 turbine fuel added and ignited. The results of these experiments confirmed that when the fuel supply was exhausted, the foam blocks self extinguished within a few minutes. Most blocks appeared to have suffered only moderate damage.

Results: The intumescent foam performed as designed, but did not leave any more solid foam in the center of the sample than the standard foam. Both foams self extinguished when the initiating fire went out. Neither foam burned very rapidly.

Preliminary Conclusions:

Neither standard nor intumescent foam ignited rapidly to produce a flash fire.

Although the intumescent foam reacted as expected, it did not appear to increase the amount of solid foam left after the burn, compared to the standard foam.

We need to experiment with larger masses of foam to determine if these characteristics carry over.

Task Order:

Use samples trimmed from large blocks of 2 pcf and 4 pcf standard foam and 2 pcf intumescent samples. Key issue is whether ignition source is on vertical or horizontal (top) surface, so need some of each. Use 2 or 3 samples of ignition sources in small quantities: ½ pint gasoline, ½ pint JP-8, a few gm of burning Comp B, etc. Use simplest ignition technique deemed safe. Video the whole.

Actual Experiments: Several series of preliminary flammability experiments were conducted to see how the foam burned. The first and most reliable experiment used about 6 oz of JP-8 turbine fuel and a cloth wick for ignition. Foam blocks of about 5 x 6 x 2 inches were floated in a pan of fresh water. Approximately 6 oz of JP-8 was floated on the water and ignited with a soaked cloth wick. This experiment was conducted twice, resulting in nearly identical burns.

Figure 11 shows this experiment being demonstrated for the TCG on December 12, 1995. Other methods of ignition, such as electrically ignited C-4 pellets and white phosphorus,

Figure 11. Ignition of JP-8 for TCG Flammability Demonstration

were tried. Both failed to provide the reliability and ease of safe ignition that the fuel-soaked wick method offered and were quickly abandoned.

In Figure 12, the JP-8 fuel is fully ignited and flames have surrounded the three foam samples. The samples under test, left to right, are 4 pcf standard, 2 pcf intumescent, and 2 pcf standard foam. The accepted time-averaged temperature for fully developed jet fuel pool fires is 1232°C/2250°F. The fire burned briskly for about 6 minutes before exhausting the fuel available. The foam blocks then self extinguished very shortly after the fire went out.

After cooling, the blocks were inspected and showed the following:

- The lower 1/8 - 3/16 inch that was actually in water survived intact; original size with no charring.

- The upper portion of the foam block was charred all over and burned to a depth of about 1/2 inch. The sides were charred to a depth of about 1/4 inch. The center of the block appeared sound. Figures 13 and 14 show the samples after the burn.

The intumescent 2 pcf sample swelled up, as expected, on those portions of the block exposed to the flame. A close-up is provided in Figure 14.

Figure 12. JP-8 Fuel Fire Surrounding Foam Samples

Figure 13. Foam Samples after Burn

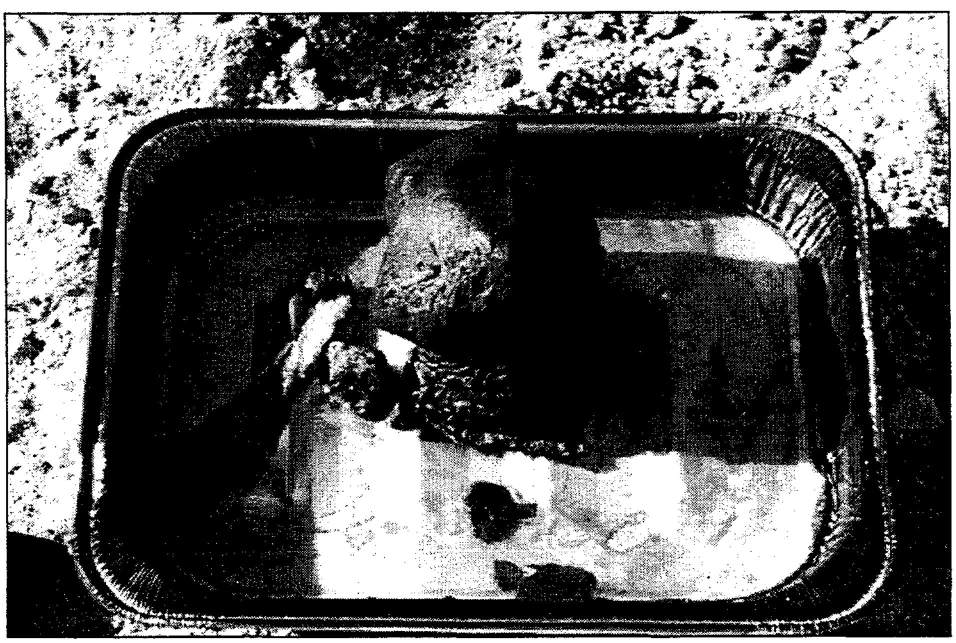

Figure 14. 2 pcf Intumescent Foam Sample Showing Swelling

Sample blocks from the first preliminary experiment were cut in half to observe the depth of charring in the foam as shown in Figures 15 and 16.

A comparison of the 2 pcf standard and 2 pcf intumescent foam photos showed the swelling along the sides of the #2/I block that is designed to reduce the fire damage by creating additional insulation.

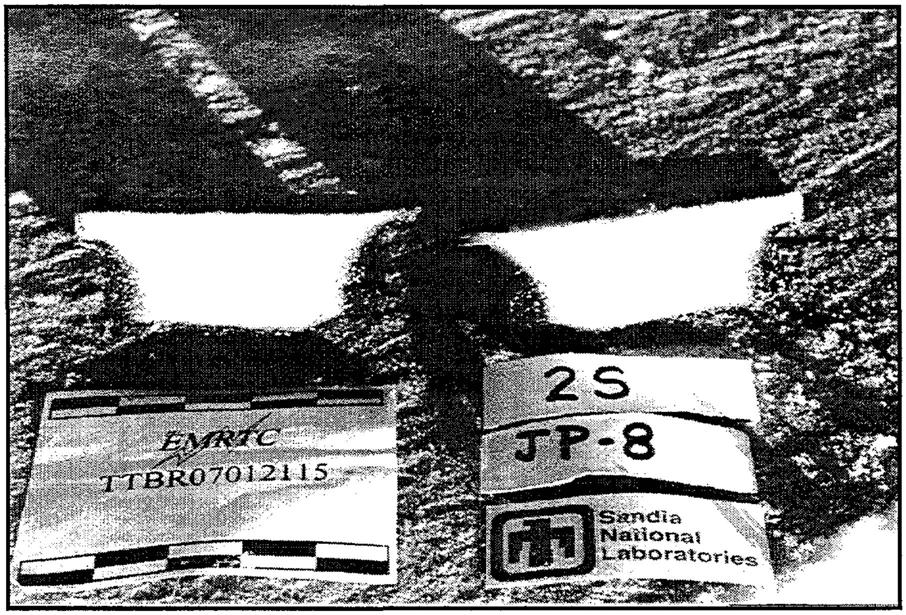

Figure 15. 2 pcf Standard Foam Sample after Sectioning

Figure 16. 2 pcf Intumescent Foam Sample after Sectioning

Operational Suitability 1.1.1

Ordnance Impact 1.1.1.1

Flammability 1.1.1.1.6

Introduction:

The preliminary flammability experiment (1.1.1.1.5) involved very small blocks of foam. It was uncertain that larger samples would react in the same manner, especially considering that the small foam blocks self extinguished almost immediately when the heat source was removed. This second experiment used both a 2 and a 4 pcf foam block wall approximately 5 ft square and 6 inches thick. The foam was ignited by a diesel oil pool fire adjacent to the wall. Thermocouple temperature measurements were recorded and the entire experiment was video taped.

Results: The entire front face of the foam wall was charred and partially charred around the sides and top including parts of the back of the wall. In the 2 pcf experiment, two holes were burned completely through the 6-inch thickness where the fire intruded into cold joints* in the foam. The foam appeared to have ignited from the radiant heat of the oil fire before direct conduction was observed. The foam did self extinguish even before the oil fire burned completely out.

Conclusions:

Two pcf Foam:

The 2 pcf foam in larger mass acts very much like the small samples.

The foam can be readily ignited by radiant energy; perhaps a useful experiment would be one directed toward determining the flux required to produce ignition.

The foam in this experiment did self extinguish as soon as the initiating fuel fire began to burn down.

Further flammability experiments with a solid poured wall will be conducted during Phase 2.

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* The "cold joints" referred to resulted from the volumetric limits of the foam dispenser at Allied Signal. To produce a 54-inch high block, three separate pours were usually required with two short delays in between while the foam dispenser was refilled. The resulting layers show voids, bubbles, and a lack of good adhesion between layers. This lack of bonding between layers became obvious during the flammability and explosive experiments. Details on foam bonding are in Appendix B, February 29 memo.

Four pcf Foam:

Similar to the 2 pcf wall burn but burned less deeply into the foam. Interior temperatures rose only slightly above ambient.

Smoke from the foam did not appear to be any worse than that from a wood and oil fire.

Further flammability experiments with a solid poured wall will be conducted in Phase 2.

Note: The prefabricated blocks provided by Allied Signal contained no fire retardant. The foam selected for on-site pour may have a mild retardant and should perform even better.

Task Order:

Construct walls (1 ea 2 pcf and 4 pcf) of ~6 inch thick blocks cut from large blocks used in Trafficability experiments. Glue with carpenter's glue. Walls to be about 4 to 5 ft high and long enough to span well past edges of water tank. Float enough diesel fuel on water to burn 5 to 10 minutes. Attach wall to edge of tank. Use thermocouples to get time history of temperature at representative locations.

Actual Experiments:

Two pcf Foam: A vertical foam wall was constructed of 2 pcf foam blocks approximately 6 x 6 x 60 inches, cut from the large blocks used in the trafficability experiments. The blocks were glued together to form a wall using water-based carpenter's glue. The 5 x 5 ft wall was mounted vertically on the edge of a 3-ft wide steel tank partially filled with water as shown in Figure 17. About 2½ gallons of diesel fuel were floated on the water and ignited with an oil soaked cloth.

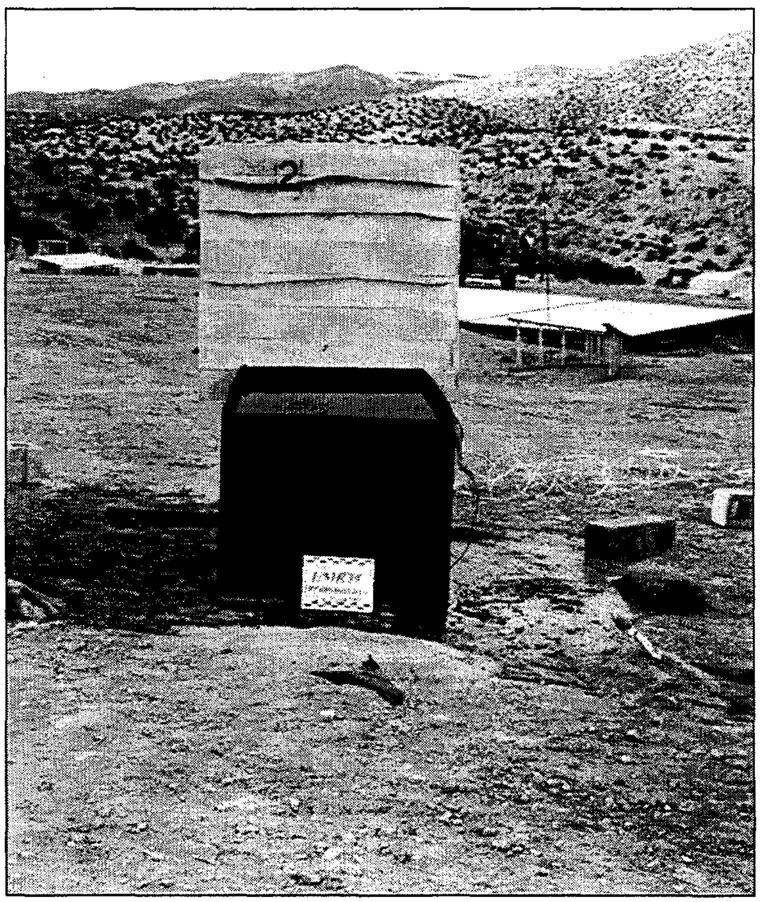

Figure 17. Flammability Experiment Setup

It took approximately 2 minutes for the oil fire to generate enough heat to ignite the foam. Interestingly, the flames were going straight up, about 1 ft away from the front surface of the foam wall, when the foam caught fire. The ignition front produced by radiant heat could be seen moving from right to left across the face of the foam wall, all the way to the edge.

The oil fire burned very hot for about 5 minutes; see Figure 18. The wind increased to about 5 to 10 mph and blew flames around the sides of the wall and up over the top, charring the back of the block around all three exposed edges. During the hottest portion of the burn, the unburned foam at the back of the block was cool enough to touch, demonstrating the excellent insulating properties of this foam. At 5 minutes into the burn, flames began to intrude into most of the construction joints between the blocks. Shortly thereafter, two holes developed at the cold joints in the foam and burned completely through the 6-inch wall (Figure 19) along the cold joint surface. Nine minutes after ignition, the oil fire began to die down. As soon as the radiant input diminished, the foam began to self extinguish and was soon only smoldering at one edge. The total duration of the experiment was ~11 minutes. Figure 20 shows the experiment after the burn. Figures 21 and 22 show the thermocouple data for both 2 pcf and 4 pcf experiments. Note that the embedded thermocouples 2, 3, 5, and 6 in the 4 pcf wall never recorded a temperature rise as they did in the 2 pcf experiment.

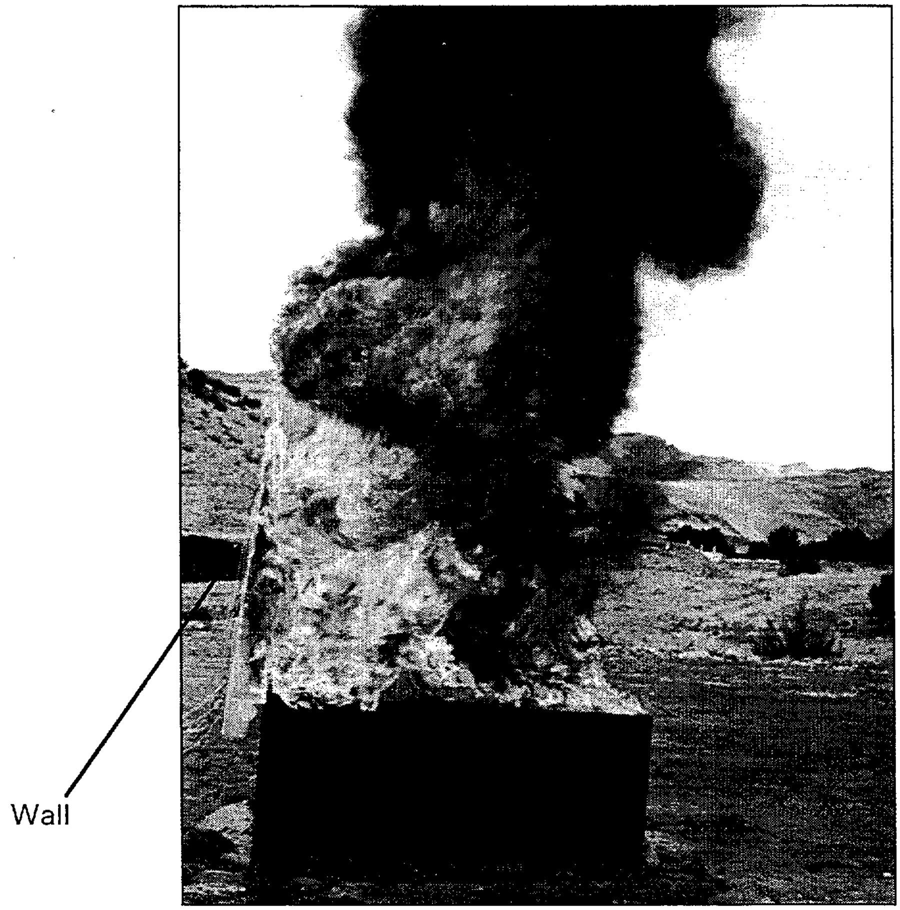

Figure 18. Full Burn after about 3 min

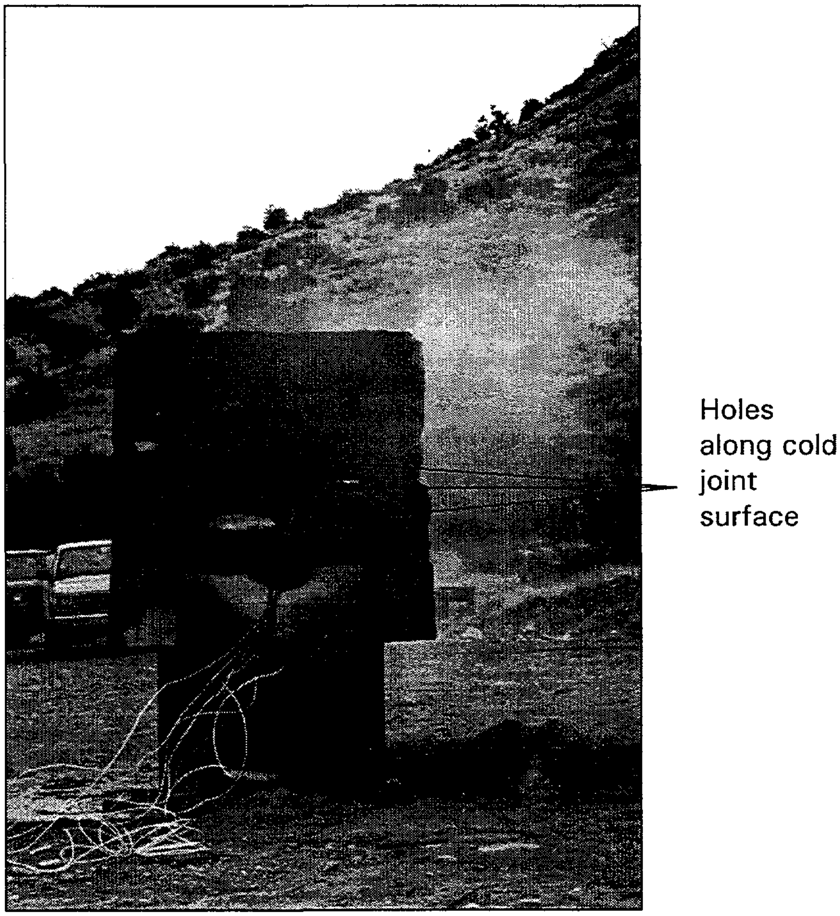

Figure 19. Rear of Block Wall (showing thermocouple cable and holes burned through the foam)

Figure 20. Completion of 2 pcf Foam Experiment

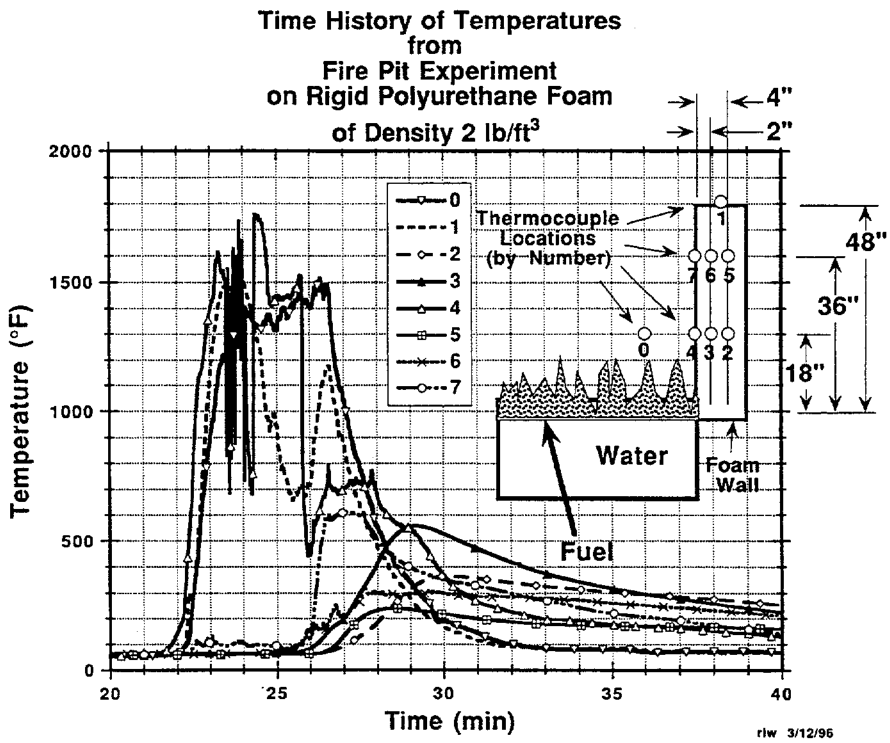

Figure 21. 2 pcf Time History of Temperatures

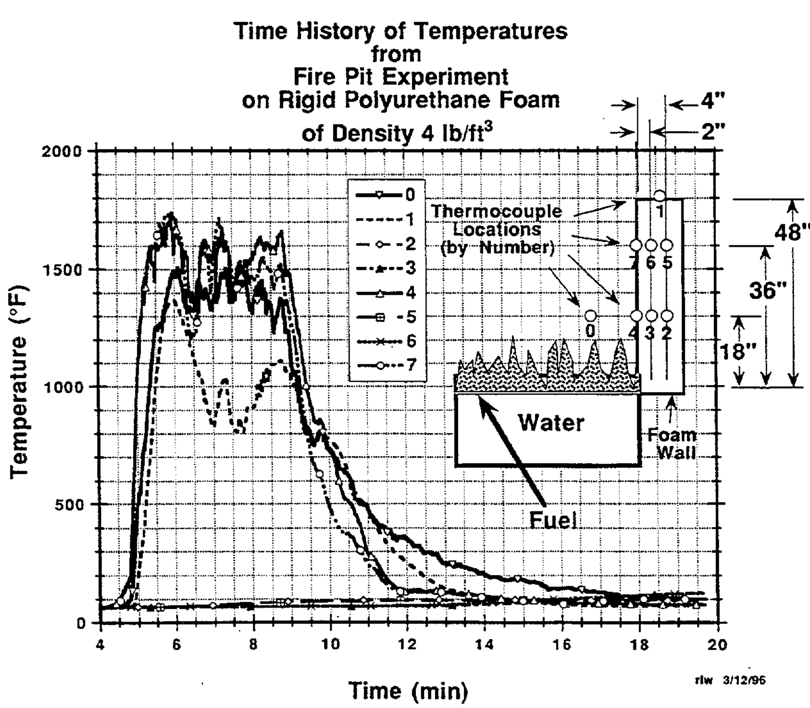

Figure 22. 4 pcf Time History of Temperatures

Four pcf Foam: A second foam wall was constructed of 4 pcf foam blocks, glued, and instrumented the same as the 2 pcf wall. It was subjected to a similar diesel oil fire. Figures 23 and 24 show the setup.

Three and a half minutes after the oil fire was ignited, it appeared to be burning well. About 10 seconds after the oil was at full burn, the foam ignited. The ignition appeared to be from radiant heating similar to the 2 pcf foam except the flame front spread bottom to top across the foam. The flames from the fire were close, but did not appear to contact the foam directly.

At time 1:18, the foam wall was burning all across the face, around the sides, and over the top of the wall (see Figure 25). The slight breeze (1 - 2 mph) that had been blowing the fuel fire toward the wall dropped to zero and, for about 1½ minutes, both oil and foam burned furiously with all products going straight up.

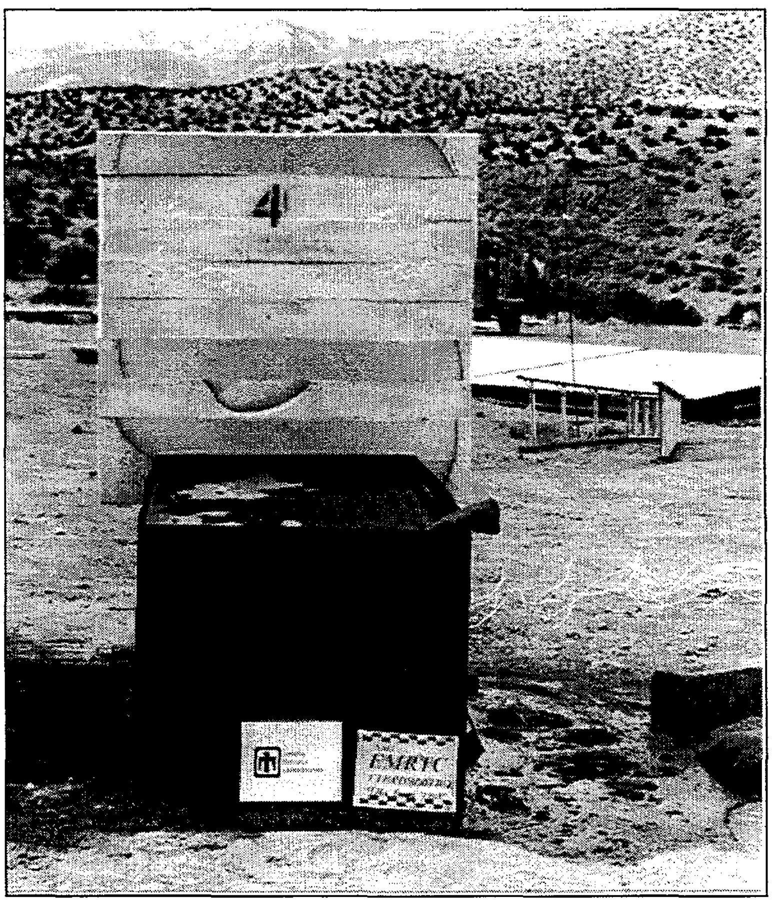

Figure 23. Setup for 4 pcf Burn

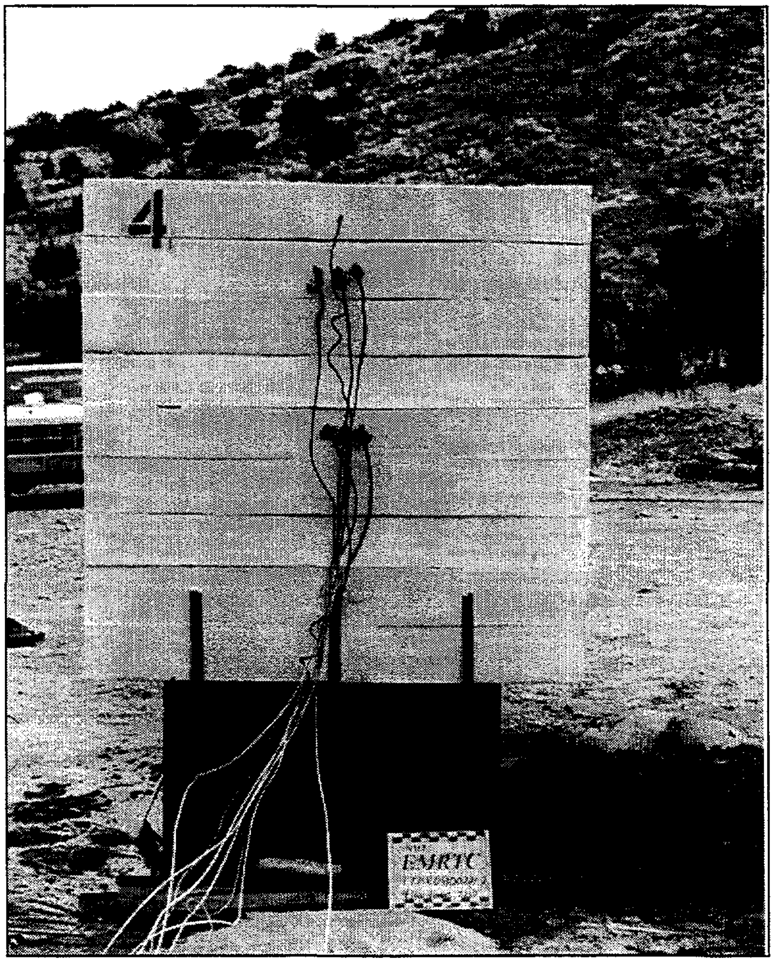

Figure 24. Back of Foam Wall (showing thermocouple placement and cables)

At about 2½ minutes into the burn, the breeze picked up to ~2 mph, blowing the fire away from the face of the wall. The front face continued to burn and flames could be seen in the construction joints between the blocks.

At time 4:30, the fuel fire began to die down. Almost immediately, the front face of the wall stopped burning, but the construction joints (or perhaps the glue) between the blocks continued to burn. At time 4:35, the construction joint at the bottom of the uppermost block burned clear through and flames could be seen on both sides as in Figure 26.

Five minutes and 40 seconds after foam ignition, the fuel fire was essentially out. The foam smoldered in the construction joints and smoked. In another 50 seconds, all construction joints were out except for one area 5 to 6 inches long in the next to lowest construction joint on the right front. This area burned for another 4 minutes. Figure 27 shows the wall at this point. Figure 28 shows the back at about the same time.

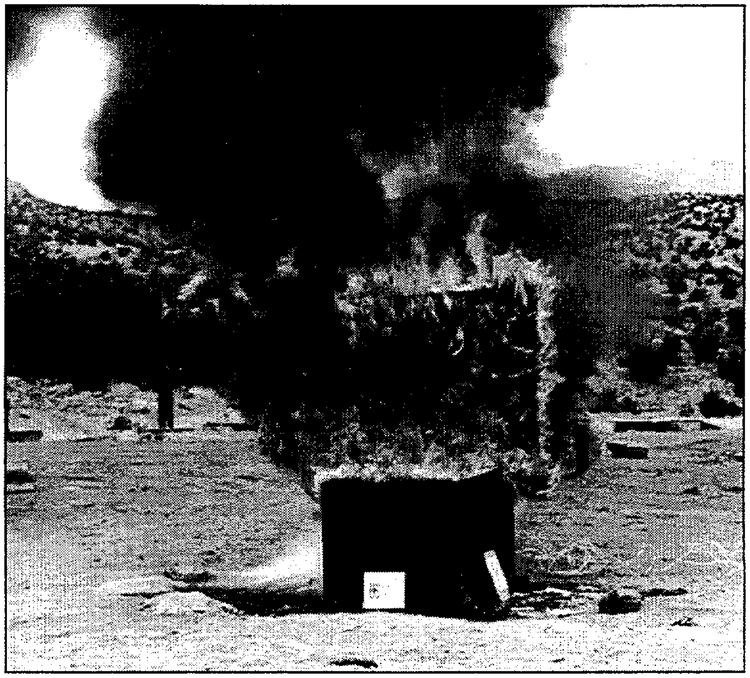

Figure 25. Full Burn (with wind-blown flames wrapping around edges)

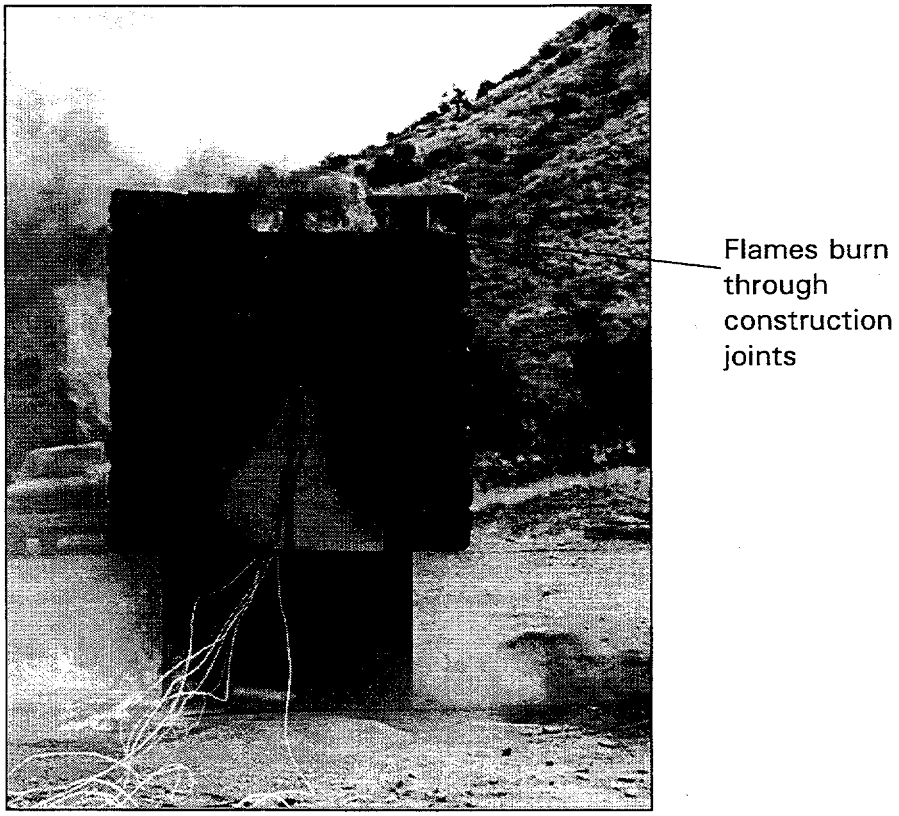

Figure 26. Back of Foam Wall (showing fire penetration of upper wall)

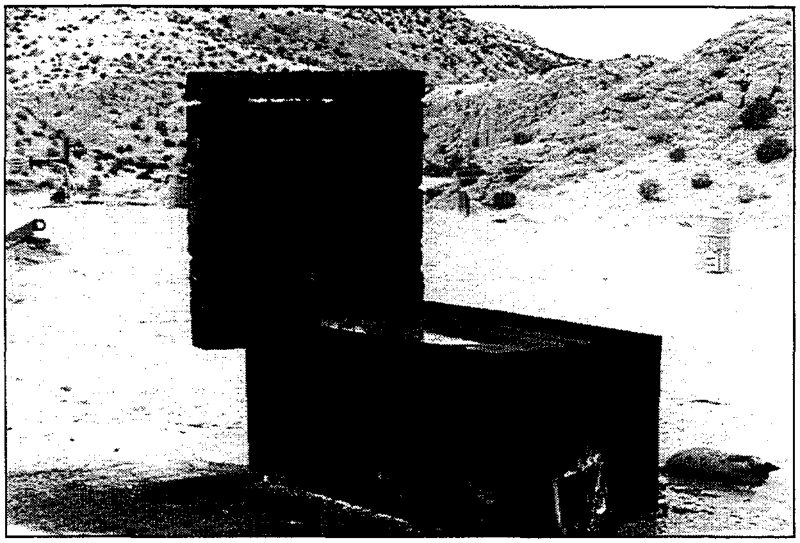

Figure 27. Fire Out

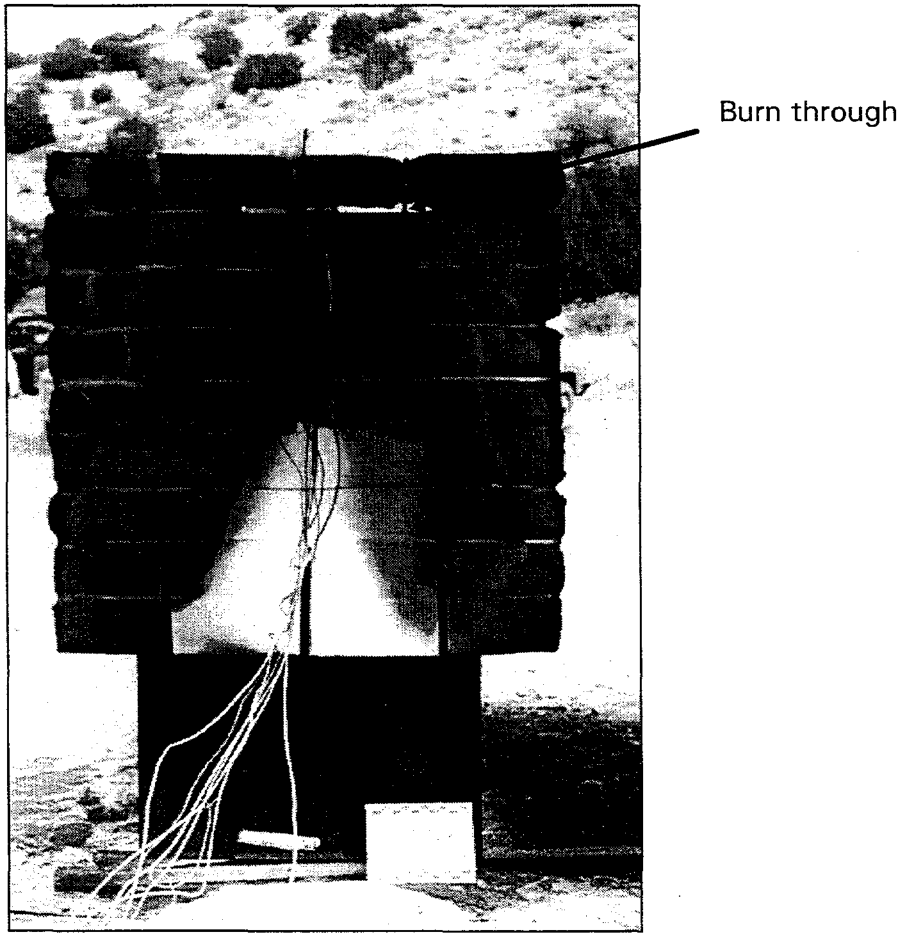

Figure 28. Back of Foam Wall (showing penetration damage)

Operational Suitability 1.1.1

Operational Tolerance 1.1.1.2

Small Explosives 1.1.1.2.1

Introduction:

In the Small Explosives series of experiments, we wanted to study cavity formation in blocks of foam caused by explosives being placed either on the surface of the block or embedded within the block, and then detonated. In doing this, we wanted to see how well the foam withstood various size charges. Previous calculations by Cooper and Kurowski of Sandia in October of 1975 were verified and their data extended empirically.

In performing these experiments, we anticipated significant damage to the blocks from the large charges. 10, 100, and 1,000 gram C-4 charges were placed on the surfaces of 2 and 4 pcf blocks and detonated. Although many of the blocks fractured catastrophically, it was still possible to determine the rough size of the cavity by reassembling the bigger fragments.

Results: Cavity sizes compare very well with predictions based on previous work done by Cooper and Kurowski. Because of the correlation, replication was considered unnecessary for this series of experiments.

		0.1 gm	10 gm	100 gm
Surface	2 pcf	~2 inches	12 inches	26 inches
Embedded	2 pcf	N/A	14 inches	23 inches
	4 pcf	N/A	N/A	28 inches

A single 1,000 gram C-4 surface shot was conducted on 4 pcf foam, block #04-01, resulting in massive block fracture and fire. The block was too small to contain the explosion but the cavity size follows the prediction.

Conclusions:

The results of these experiments reproduced the work of Cooper and Kurowski for embedded charges and extended the data to indicate that cavity sizes produced by surface explosions were equally well predicted by their work. There was no observed difference in cavity size between embedded and surface explosions.

Experimenting with charges larger than 100 gm will have to wait until larger blocks can be poured. To keep a 4 pcf foam block intact, the block must be large enough that the distance from the charge to any free side is greater than several times the diameter of the cavity formed by the exploding charge.

Task Order:

Use C-4 embedded in center of undamaged remains of 54-inch cube; 10 gm and 100 gm shots. Use 2 pcf or 4 pcf blocks as available. Section after shot to measure crater. Brad Hance will direct cutting of samples for laboratory examination. Repeat for top surface crater; embed charge so that its upper surface is tangent with the upper surface of the block.

Actual Experiments:

Foam blocks of 2 pcf and 4 pcf density were subjected to explosive charges ranging from the RP-80 electric detonator to 1,000 grams of C-4; both as surface shots and with the charge embedded to half the thickness of the block. Both the 2 and 4 pcf foams showed good damping of explosions. Charges of 10, 100, and 1,000 gm of C-4 were fired on the block's surface and embedded charges of 10 and 100 gm were fired in both 2 and 4 pcf foam. Three of the explosive experiments were documented as follows:

Two pcf Foam:

Charge: 100 gm C-4 embedded at 27 inches

Receptor: Foam block #02-03, 2 pcf density, complete as shipped

Procedure: Block 02-03 was set upright on its pallet and a hole bored straight down 24 inches from each of two sides. The charge hole was bored out to 27 inches in depth to allow 3 inches extra to account for the irregularity of the top surface. A plug for the charge hole was taken horizontally from the corner farthest from the bore hole (A), parallel to the base of the block as shown in Figure 29. The 100 gm C-4 charge was primed and lowered to the bottom of the charge hole and fired. Figures 30 and 31 show block #02-03 before and after firing.

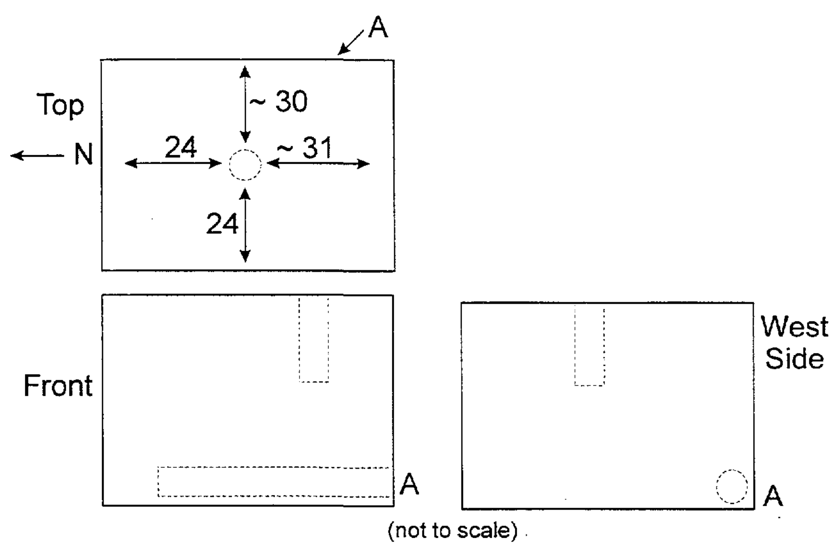

Figure 29. Diagram of 2 pcf Small Explosive Experiment

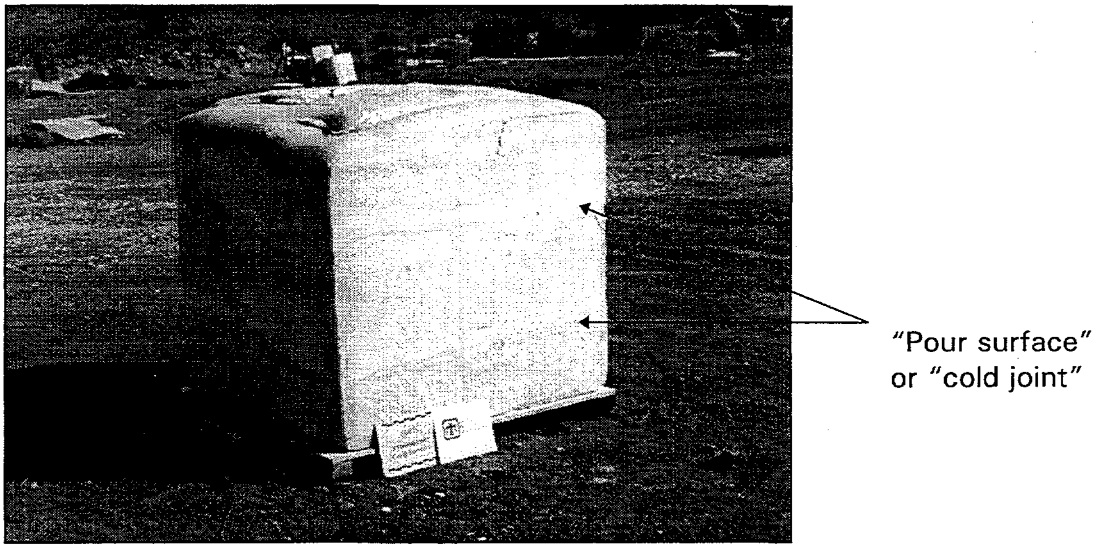

Figure 30. Block #02-03 Setup for 100 gm Embedded Shot

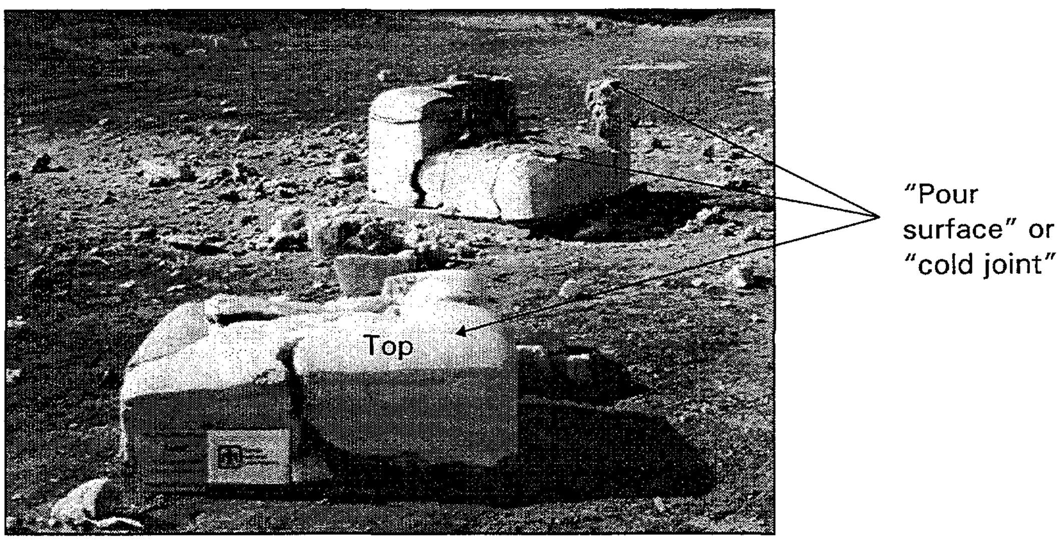

Figure 31. Block #02-03 following 100 gm Shot (top layer in foreground)

Results: On firing, the upper two-thirds of the block were blown apart, resulting in fragments from bushel basket size to powder. The majority were fist size or smaller. The block fractured along the line of the first of three pours. (See page 23 for discussion of the effect of "cold joints.") More damage was noted on the south side of the remaining foam and the corners of the second pour level were broken but still in place. The bigger segments were reassembled and three cavity measurements were taken of 25½, 21, and 21½ inches in diameter. Best estimate of cavity size is about 23 to 24 inches in diameter.

Note: It appeared that this block fractured along the lower pour line due to a cavity at the bottom of the second pour. Pressure required to bore the charge hole was inconsistent and at least one small cavity was encountered while drilling to 27 inches.

Note that in Figure 31 the block failed in three distinct layers. This appeared to be due to cold joints developed between the layers that resulted from a three-stage pour of the block. Figure 32 shows the cold joints visible in the rear side of the same block, before firing.

In contrast to the embedded shots, which were too powerful for a 54-inch block to survive, the surface detonations left the blocks reasonably intact. Cavities varied from about 12 to 26 inches in diameter in the 2 pcf foam. Figures 33 through 36 show the setup and results of 10 gm and 100 gm surface shots.

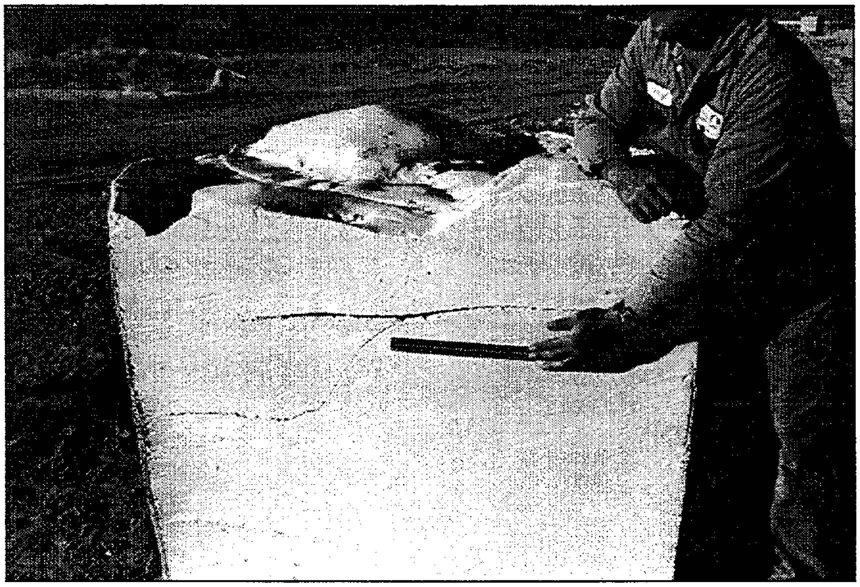

Figure 32. Block #02-03 Showing Cold Joints between Pour Layers

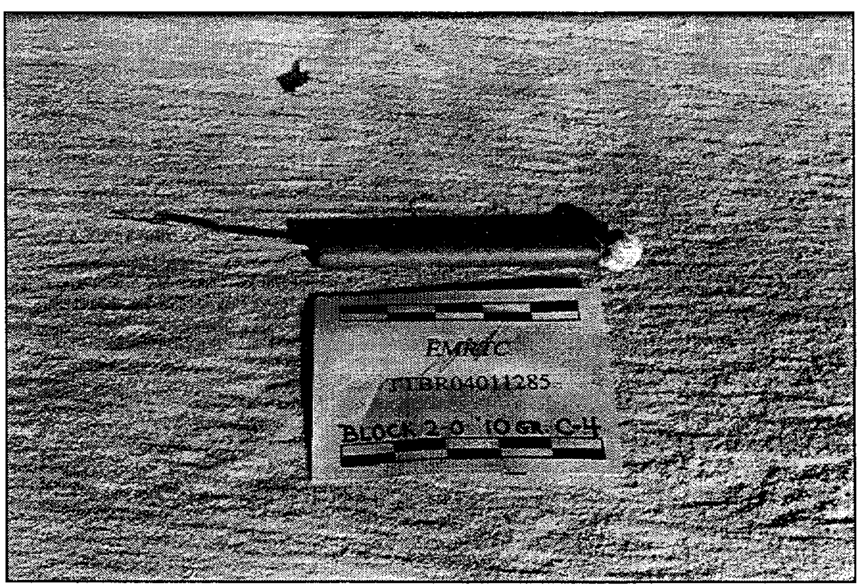

Figure 33. Block #02-00 Setup for 10 gm C-4 Surface Shot

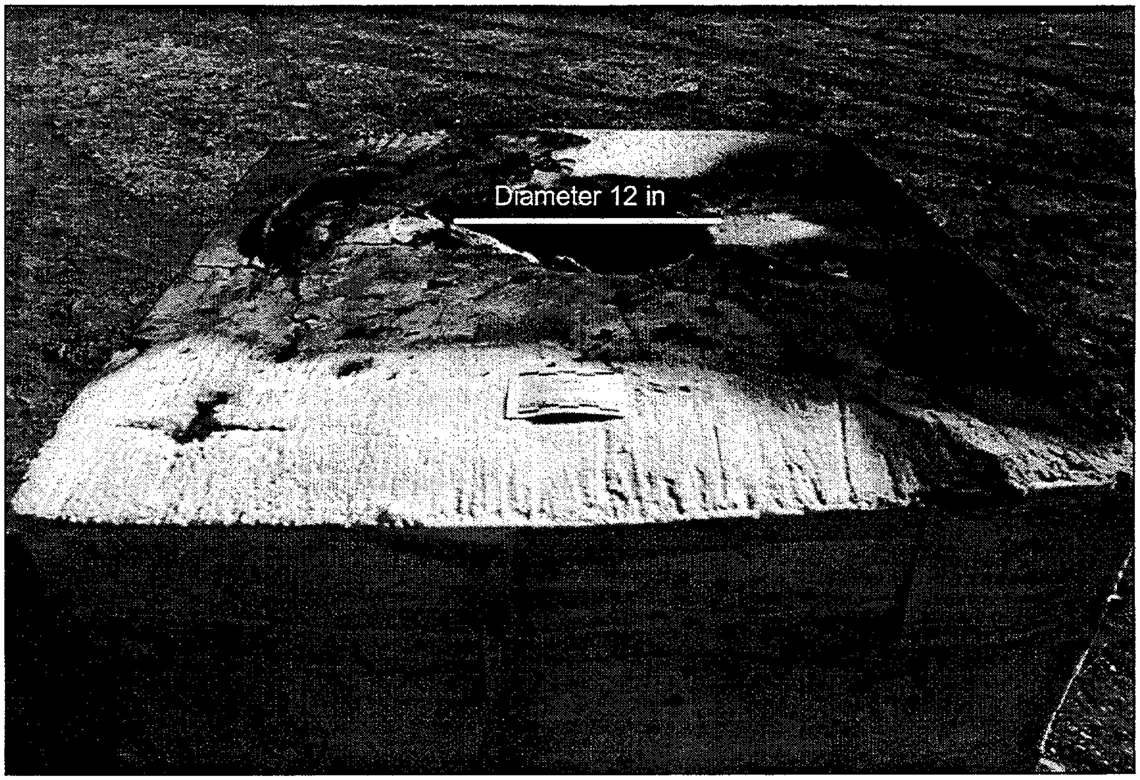

Figure 34. Block #02-00 following 10 gm C-4 Surface Shot

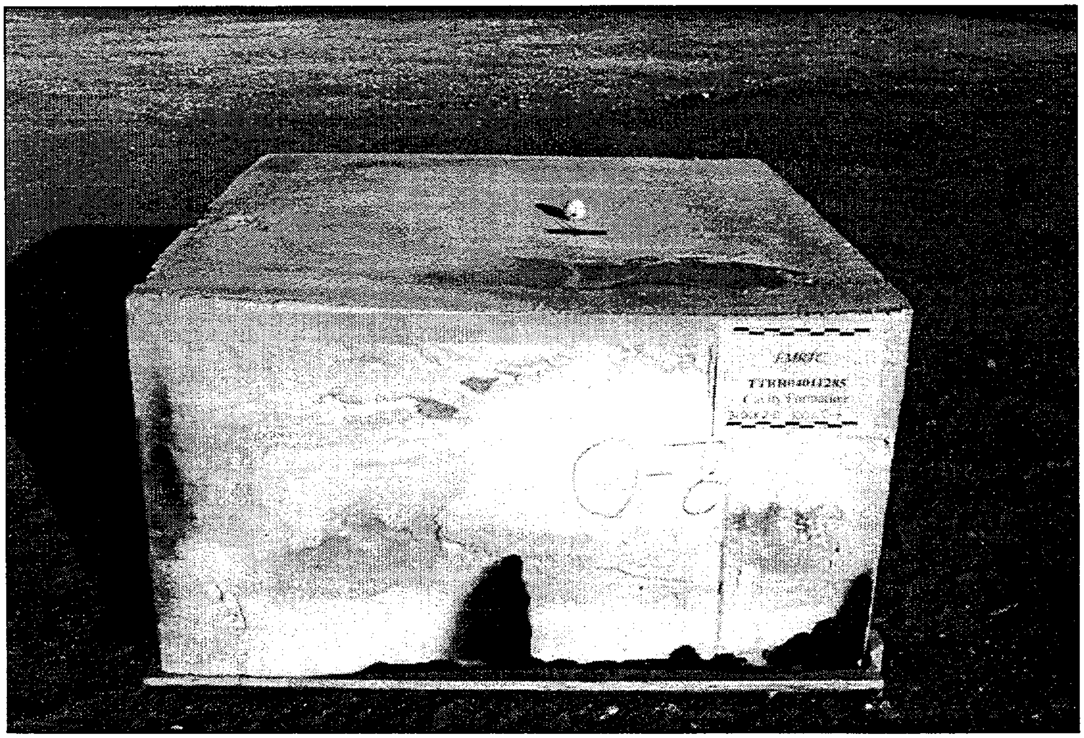

Figure 35. Block #02-00 Setup for 100 gm C-4 Surface Shot
(burn at bottom is from 10 gm shot)

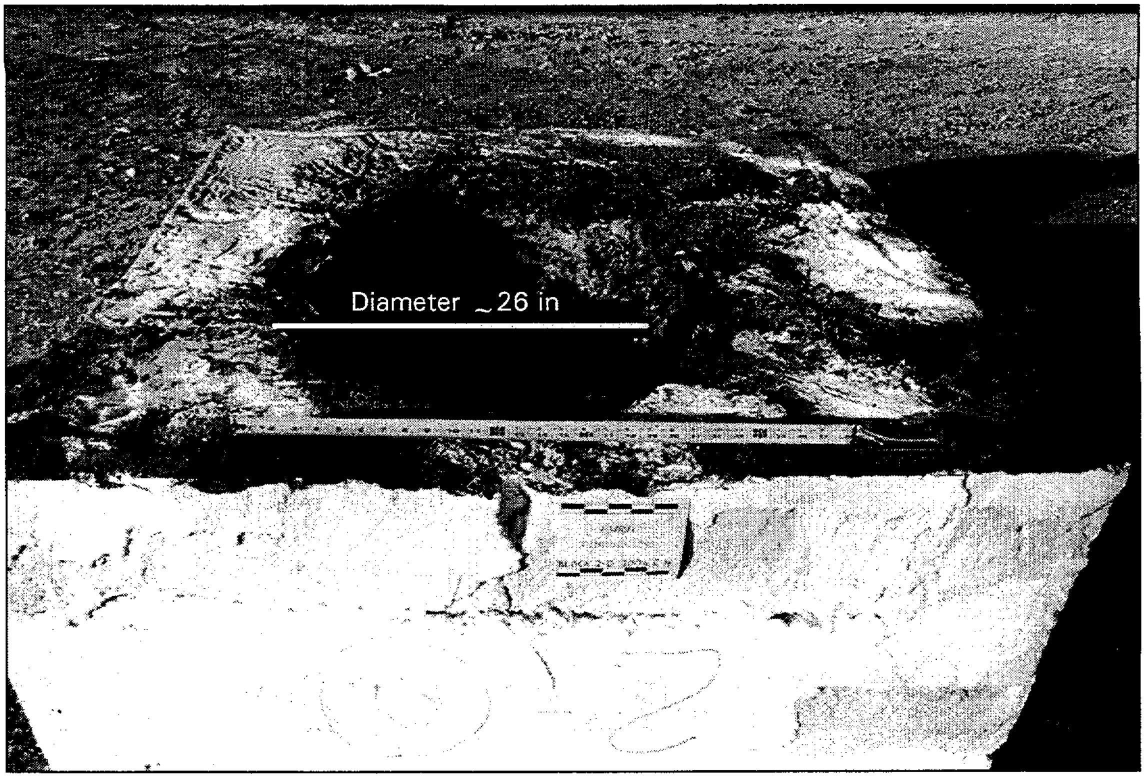

Figure 36. Block #02-00 following 100 gm C-4 Surface Shot

Four pcf Foam:

a. Charge: 100 gm C-4 embedded ~ 18 inches down into the approximate center of 4 pcf block

Receptor: Block #04-02 remnant ~ 35 H x 54 W x 54 inches L (previously used in trafficability experiment)

Procedure: Block #04-02 was the block used for a trafficability experiment with the M60 tank making 32 passes. It had one obvious crack across the block from N to S when emplaced. The crack varied from hairline to about 3/16 inch and depth was not determined. The block was bored to 18 inches for a 100 gm charge and two plugs were cut from the SE corner, as shown in Figure 37. The initial firing resulted in a low order/incomplete detonation. The range was cleared and charge remnants removed by picking out the plug and carefully reboring the charge hole. A small cavity was observed at the point of the charge placement that was roughly estimated at 4 to 6 inches in diameter. No other damage was apparent after the first firing.

Two more plugs were cut from the same (SE) corner and a second 100 gm C-4 charge was brought up and assembled. The second charge was inserted to about midpoint (vertical) and fired high order.

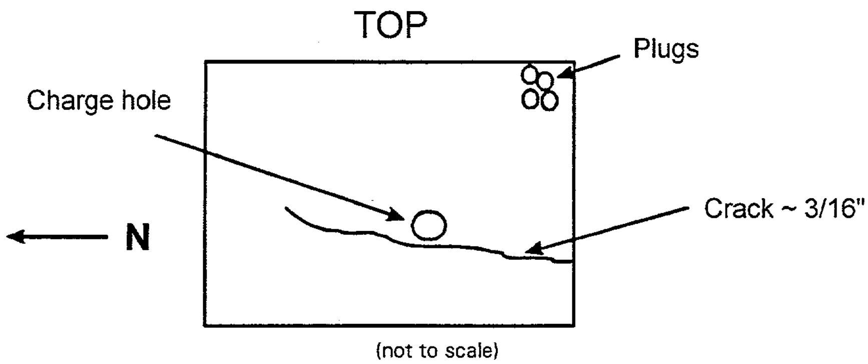

Figure 37. Diagram of 4 pcf Small Explosive Experiment

Results: The block was blown apart in a large number of big fragments showing very little scorching and no fire. Fragments ranged from ¼ to 2+ ft^3 and one large piece remained attached by the shipping cardboard. On reassembly, the sides were basically all accounted for and showed a cavity of 23 inches at the first pour level, 34 inches at the top of the second pour, and an estimated cavity diameter of 28 to 30 inches at charge level. The obvious crack had opened and may have allowed some extra venting. The block appeared to have also fractured along the line from the NW to SE corners. Figure 38 shows the debris from this shot.

Figure 38. Block #04-02 following 100 gm C-4 Embedded Shot

b. Charge: 1,000 gm C-4 spherical on center of top (cut) surface

Receptor: Lower three-quarters of block #04-01; 4 pcf 34 inches (front) 38 inches (rear) in height

Procedure: Block placed upright on pallet with cut surface uppermost. The C-4 charge was primed and placed in appropriate center of the top surface. Cardboard packing around at least three sides was left in place. The charge was electrically fired.

Results: On firing, the block was about half destroyed. Some of the foam continued burning, as did most of the cardboard packing. The major portion of the burn was extinguished using a fire extinguisher and dirt. Smoldering portions were put out with water from a small fire truck a few minutes after the shot. This was done to permit measurement of the cavity.

Some portions of what appeared to have been the top were thrown clear unburned. The lower half of the block was scorched/blackened all around. The east and west sides had collapsed outward, hinged by the cardboard. Numerous pieces were thrown 30 to 45 ft from the block. Breakup ranged from powder to sections ~ 6 x 6 x 24 inches.

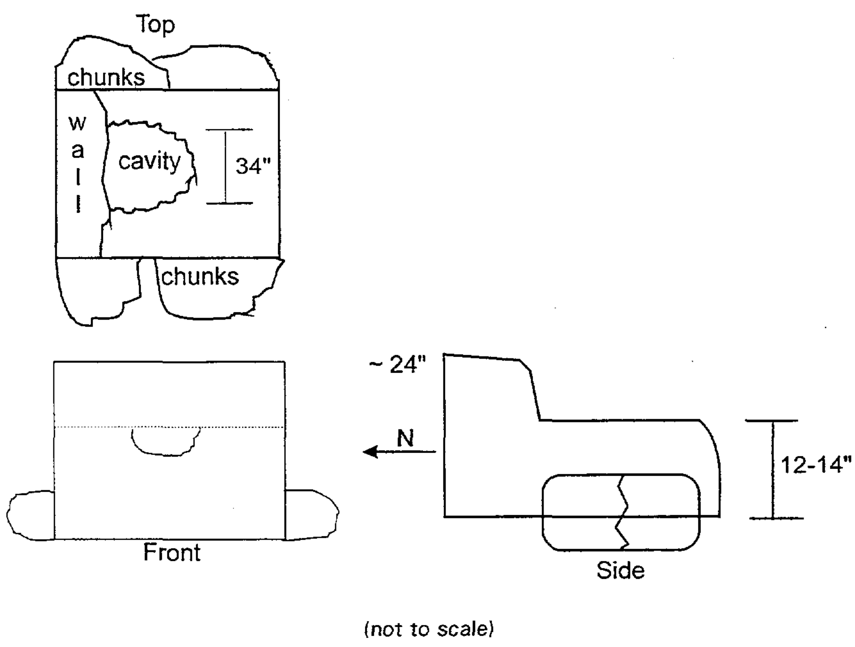

Figure 39. Results of 1,000 gm C-4 Experiment

The north side retained one "wall" that stood above the base by about 12 inches. The remainder of the block was blown away, leaving a base 12 to 14 inches thick. The portions of east and west sides were set back in place and a roughly square cavity was apparent ~ 34 inches across its widest part, as shown in Figure 39. Figures 40 through 42 show the setup and result of this experiment. Figure 43 shows the recorded cavity sizes superimposed on the plots of Cooper and Kurowski's data.

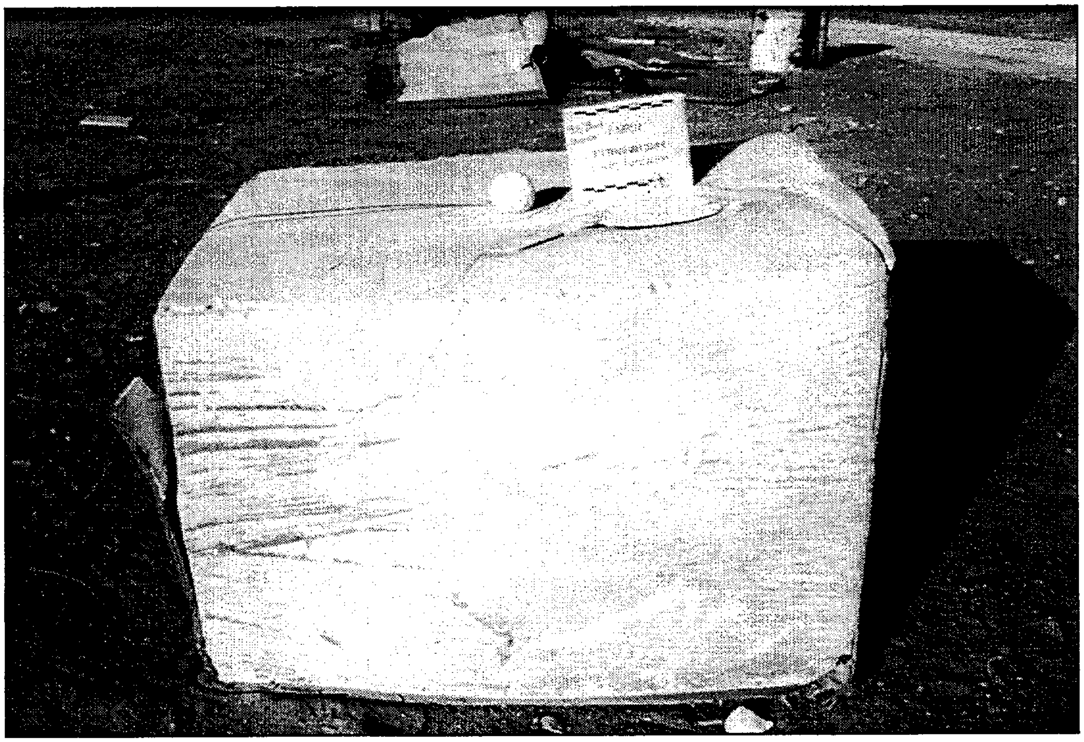

Figure 40. Block #04-01 Setup for 1,000 gm C-4 Surface Shot

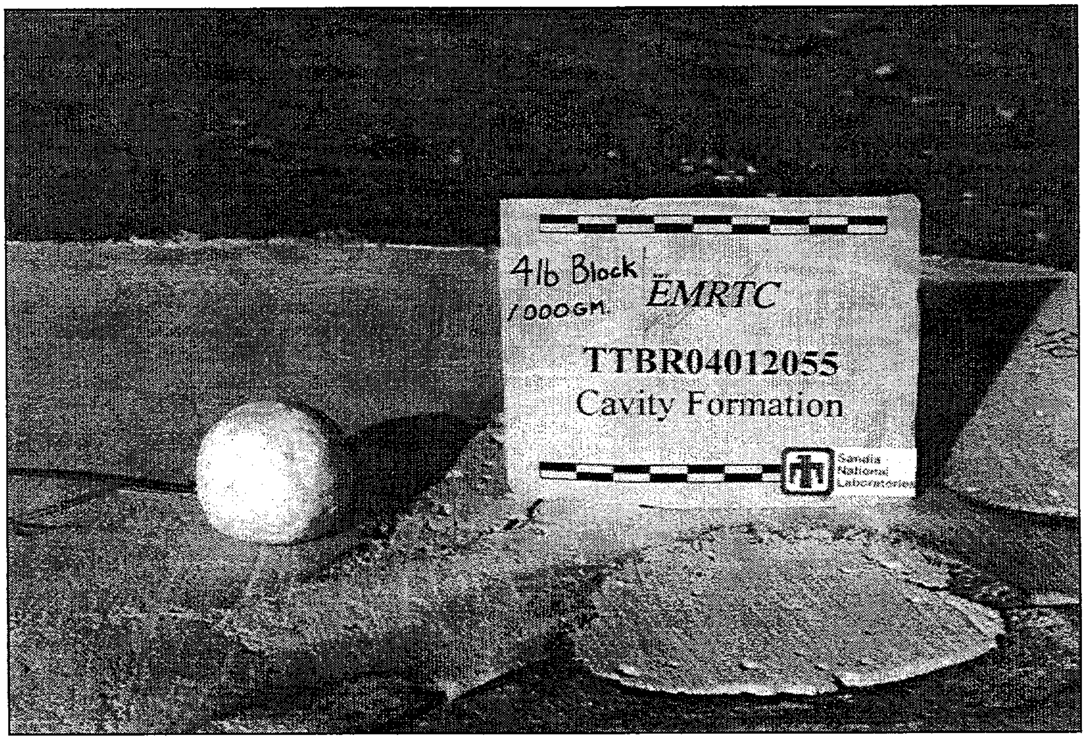

Figure 41. 1,000 gm C-4 Charge (baseball size)

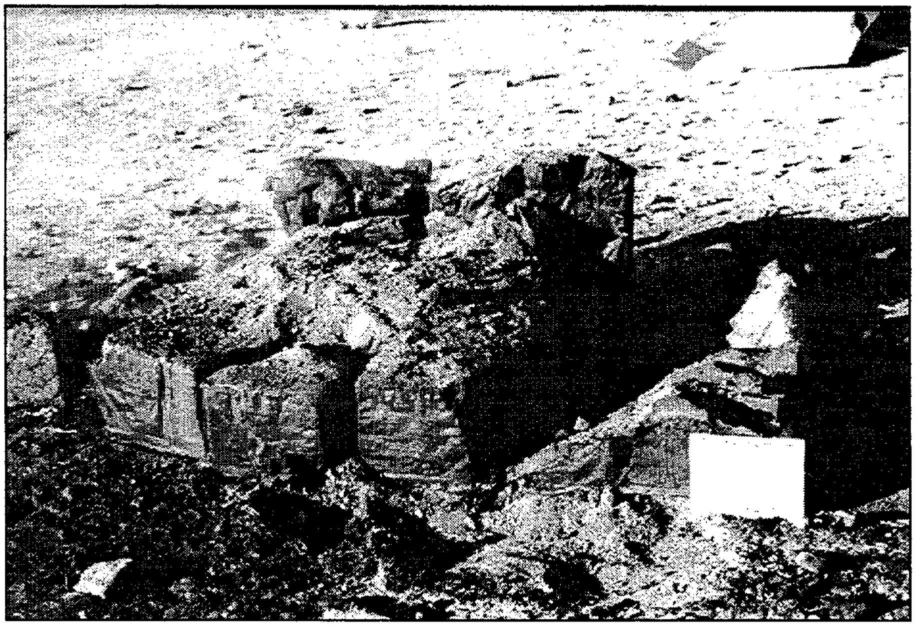

Figure 42. Block #04-01 following 1,000 gm C-4 Surface Shot

Note: A kilogram of C-4 is too much for a 54-inch block to contain. This charge would approximate the fill in a 75 mm/3 inch projectile; however, vertical extent of the severe damage only extended downward about 2 ft from the burst point.

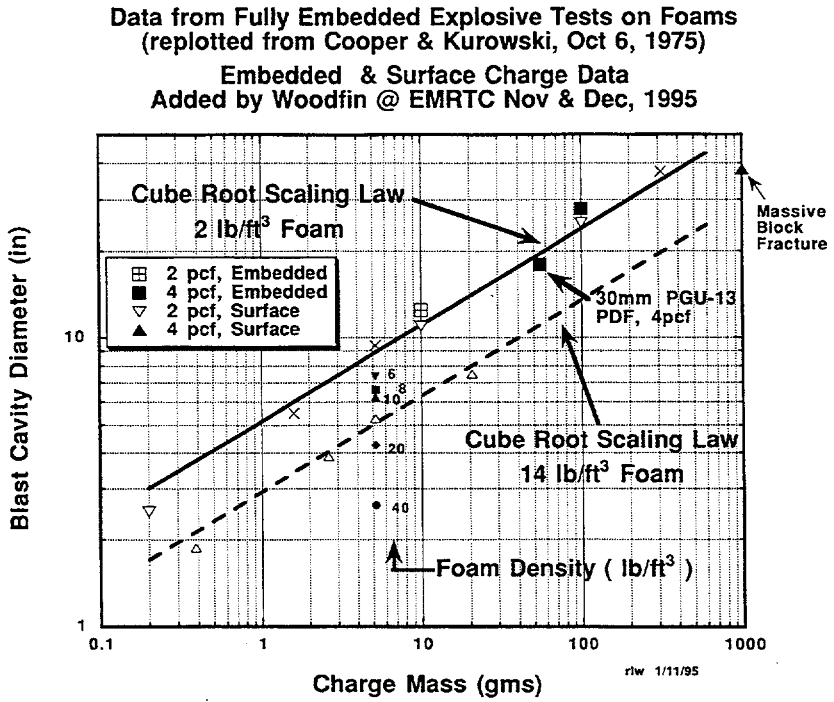

Figure 43. Embedded and Surface Charge Data

Interpretation of Results:

Development of the cavity and fracturing of the block are nearly independent processes. At this stage of the research, the apparent explanation is that the cavity is produced within the region where the blast wave energy level is sufficient to cause rupture of the foam cell walls. At greater radii, the cell walls may deform but do not rupture producing only a local failure.

The pressure loading on the block as a whole may be sufficient to cause global fracturing in the size blocks used, independent of the cavity formation. Larger blocks should contain larger explosions. Analysis of these failure modes is continuing.

These experiments showed us the detrimental effects of cold joints in the pour, even more vividly than effects seen in the trafficability and flammability experiments. Laboratory work was initiated to study the problem and quickly disclosed that the timing between the pours was critical. Results of the lab work show that the 10 to 12 minutes of delay used by Allied Signal between pours was near the worst case for cavity formation and poor adhesion between layers.

Operational Suitability 1.1.1

Operational Tolerance 1.1.1.2

POL Compatibility 1.1.1.2.4

Introduction:

In the petroleum, oil, and lubricants (POL) series of experiments, we attempted to determine how the foam would react to being immersed in a variety of chemicals and exposed to ultraviolet (UV) radiation from the sun. We wanted to determine whether there would be any disintegration or weakening of the foam after exposure to these elements. This aspect of its life expectancy is important to understand due to its many potential applications, both militarily and commercially.

Results: After one week of observation, none of the samples showed any sign of degradation. The foam did not dissolve, become crumbly, or lose any appreciable strength. This could indicate that the foam may be able to withstand being painted for protection or camouflage purposes. It also may not be damaged by the various types of spills from vehicles in either military or commercial applications.

Conclusions:

After one week of contact with the three selected POL products: lube oil, antifreeze, and fuel, neither the 2 pcf nor 4 pcf foam showed any sign of degradation. The oily products did not penetrate to any discernable depth. The foam did not dissolve, become crumbly, or lose any appreciable strength. After approximately two months immersion, the lower edge of the foam blocks showed a very slight radius, perhaps 1/16 inch. No strength degradation is apparent. If a foam ramp will be required to remain solid for 3 to 4 days, these simplistic experiments indicate that vehicle drips and leaks should present no problem. After several weeks, the paint products had produced no reaction in the foam. Paint coverage was adequate considering the very porous nature of the cut foam surface. The UV portion of the experiment was terminated after a month as inconsequential.

Task Order:

Use pieces of foam trimmed from edges for samples. Protect from UV until exposure test. Samples ~6 inches square. One sample each of cut and skinned foam for each test. POL & Paint: cover about half of one surface of each sample, leave in dark place until after TCG, then place in sunlight for 1 year. Label all samples carefully including # pcf.

Actual Experiments:

Assumptions:

- A foam ramp from the surf line to the high water line will be exposed to drips/sprays of the POL products used in AAV/AAAV/LCAC during their passage.
- Troops may want to use slabs of foam as protective shelters from observation and the elements.

Because the foam may be degraded by POL products and is known to degrade from UV exposure, these areas should be investigated.

Procedure:

Three samples each of 2 and 4 pcf foam approximately 4 x 4 x 2 inches were center bored 1½ inches to increase surface areas exposed to the fluids. The samples were placed in ¼ to ½ inch of hydrocarbon jet turbine fuel (JP-8), TECTYL 15W40 (lubricating oil/AAV-7), and a 50/50 mix of methanol and fresh water (coolant/antifreeze/AAV-7). The materials used were recommended by the AAV/AAAV project office and the USMC vehicle maintenance shop at Barstow, CA. JP-8 was substituted for the JP-5 normally used in both AAV and LCAC due to local availability and on the advice of Kirtland AFB POL QA shop. Figure 44 illustrates this experiment.

Blocks of both 2 and 4 pcf foam approximately 4 x 4 x 10 inches were painted on the outboard ends; one side with common (locally available) white, latex, house paint and the other end with drab green camouflage paint produced to MILSPEC MIL-C-53039 for use in USMC vehicle repair shops (the only paint known to be available to a Marine Corps landing force). The center 3 to 4 inches of each block were left exposed to degrade from normal UV exposure.

The blocks were nailed to a 4½ ft square pallet and were exposed to sun, wind, and weather for one month. Figure 45 shows the JP-8 samples after about a week.

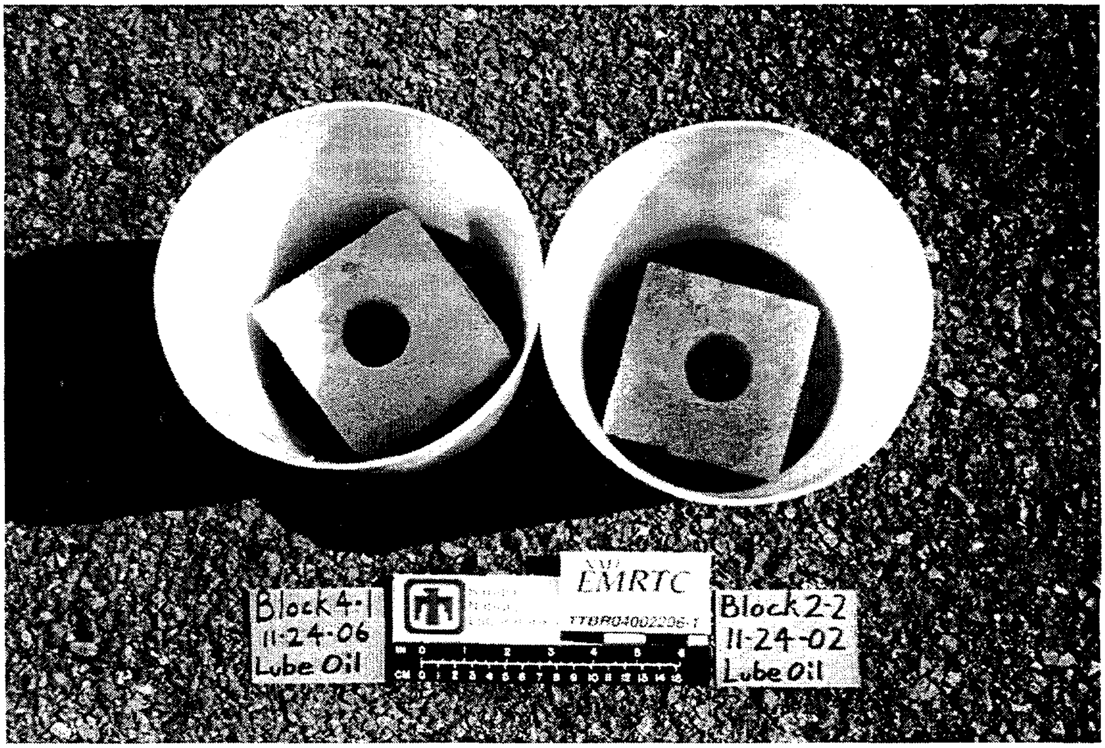

Figure 44. 2 and 4 pcf Blocks in Lube Oil

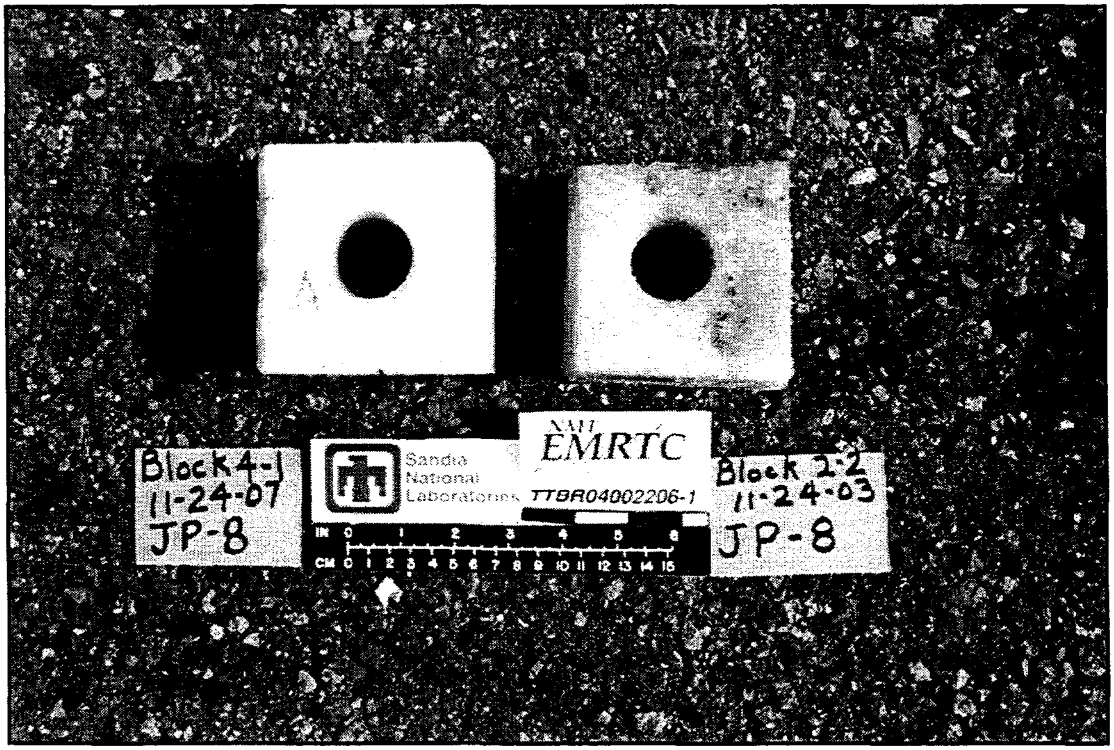

Figure 45. 2 and 4 pcf Samples

Suitability 1.1

Chemical 1.1.2

Standard Foam 1.1.2.1

Introduction:

Rigid polyurethane foam is proposed to form a passageway over obstacles on a barricaded beach, covering both the shallow surf zone and the beach itself. One of the most important properties for this application is formability in water. In addition, in a combat situation, it would be necessary to be able to use the foam as soon after pouring as possible. To determine how quickly the foam would be usable, its rise time, tack free time, and its mechanical strength as functions of temperature and of time after pouring were evaluated. The formation of interfacial voids, or faults between foam pours, were also investigated in order to prevent their formation in future foam pours.

Initial characterization studies performed on the foam examined the rise time of the foam, its tack free time (the time until the top of the foam is no longer sticky), its mechanical properties as measured by compressive strengths, and the foam's performance when immersed in water. Variations in water temperature, component temperature, and variation in mixture were also studied after the best candidate was selected.

Results:

The mixed foam components are higher in density than water and, therefore, sank when poured into the water. In all cases, water immersion slowed the foam formation. Cooler water temperatures had the most dramatic effect, with rise time and tack free time increasing substantially with cooler water temperatures. As would be expected, the reactivity increased and the density decreased with the increasing temperature of the foam components. Warmer foam caused shorter rise time and tack free time. However, none of the environments studied stopped the foam from foaming, including an improper mix ratio. (Reference: Memo from P. B. Rand and B. G. Hance to R. L. Woodfin dated January 11, 1996, in Appendix B)

Conclusions:

The behavior of the standard foam during its formation was satisfactory under all conditions within the range of these experiments. It should, therefore, prove possible to adapt these materials to the desired use.

Task Order:

Determine effect of foam component temperature on the foam's initial rise time and tack free time. T = +40/+60/+80°F. Determine effect of water temperature on foam's initial rise time and tack free time. (Batch size dependent.) T = +40/+70/+80°F. Determine the effects of various component mix ratios on compressive strength of the foam. Mix = ±10% & 20% parts A and B components. Test for correct ratios.

Actual Experiment:

To study the results of how foam would react when poured into water, 207 gm of foam components were mixed for 25 seconds using a "Conn" blade mixer. The foam was poured into the water immediately after mixing. In these water immersion tests, the mixed foam components were poured in the temperature-conditioned water and allowed to foam. The water temperature was controlled using a coiled copper tube heat exchanger in the water bath. Tests were conducted at water temperatures of 40°, 60°, and 80° F. The density of the water immersion samples was determined from core samples taken from the cured foam. In other tests, mixed components were poured into a half-gallon tub and allowed to foam Foam reactivity was determined by measuring the rise time and tack free times of the foam. "Cup" densities were obtained in these tests by determining the density of the foam in the half-gallon tub. To evaluate foam component temperature, we mixed and foamed temperature-conditioned foam components which were heated or cooled in an environmental chamber. The sensitivity of the foam system to improper mix ratio was evaluated by varying the amount of "B" component used in the mix process. Figure 46 shows the results of varying water temperature from 40° to 80°F. Figure 47 graphs the effect of different component temperatures and Figure 48 graphs the changes due to mix ratio changes.

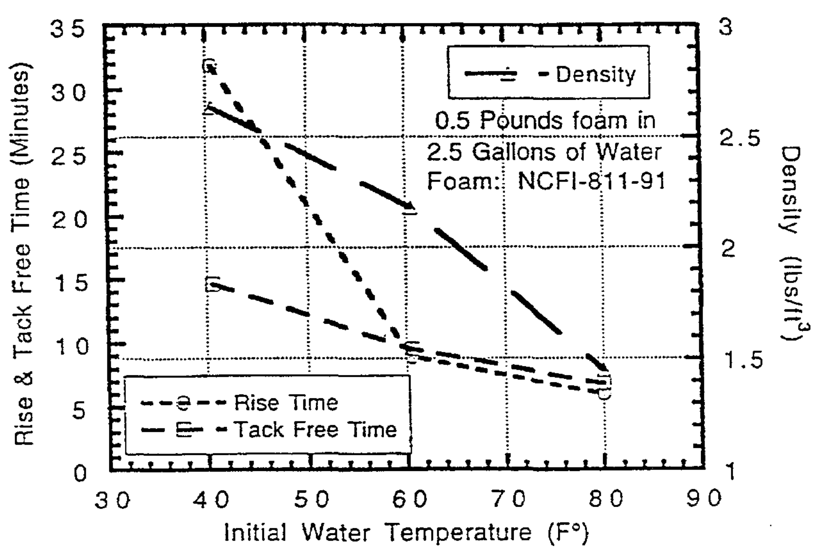

Figure 46. Effect of Water Temperature on Foam Reactivity and Density

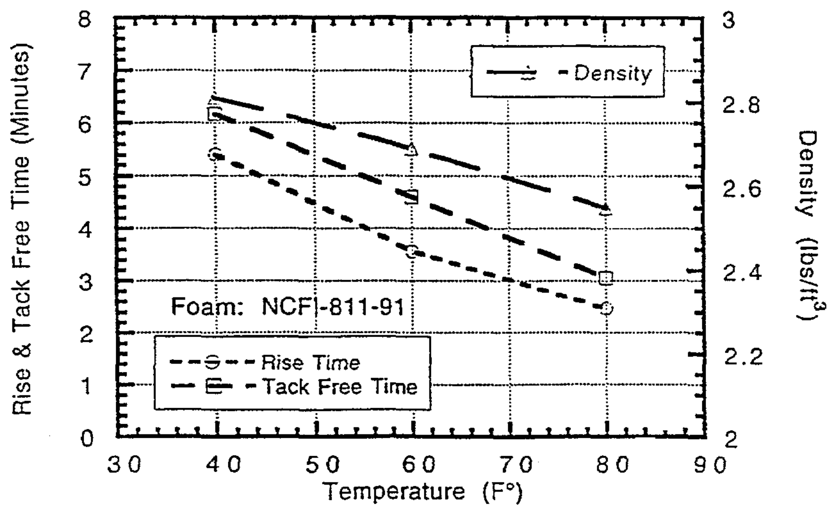

Figure 47. Effect of Component Temperature on Foam Reactivity and Density

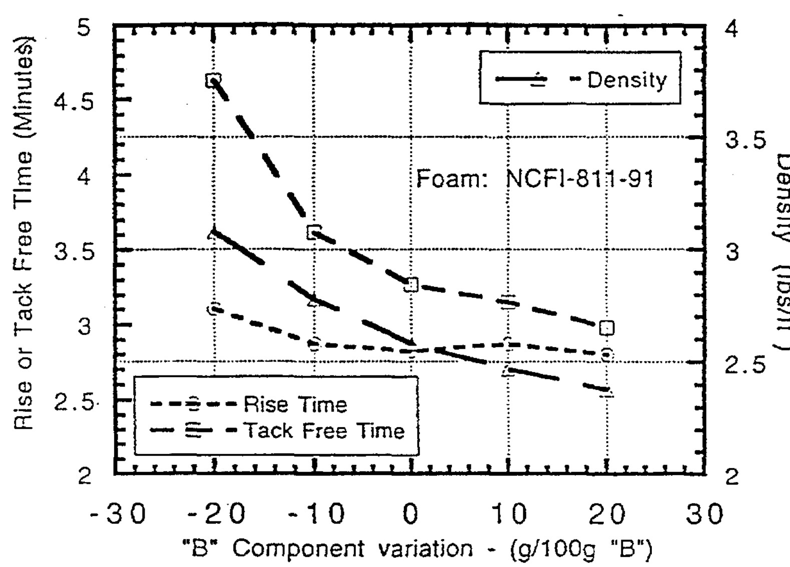

Figure 48. Effect of Component Ratio on Foam Reactivity and Density

Suitability 1.1

Chemical 1.1.2

Intumescent Foam 1.1.2.2

Introduction:

Intumescent polyurethane foams are a special class foams formulated to form protective foam chars in a fire or other high temperature environment. When exposed to a high temperature, the decomposing liquid on the foam's surface re-foams and carbonizes. This process leaves a protective carbonaceous foam layer on the surface of the foam. Intumescent RPFs were developed for use in shipping containers for nuclear materials. Many full-scale fire tests have proven their value. More common are intumescent paints, again used for fire protection.

Concerns about the flammability of rigid foams for combat applications led to the evaluation of an intumescent foam for this purpose. Because intumescent foams form self-protecting carbonaceous chars when exposed to high temperatures, it was thought these foams may be more appropriate to the combat situations in which they will be used. As with the standard polyurethane foam, the effect on foam component temperature on foamability and foam properties such as rise time and tack free time was evaluated. In addition, water immersion tests were run.

Results:

As expected, the reactivity as measured by the rise time and tack free time increased with increasing component temperature. The density decreased with increasing temperature. This effect is almost linear with temperature for all variables. We found that the foam quality was good for all samples studied.

The intumescent foam's performance in water is a concern. When immersed in room temperature water, it foamed poorly and yielded brittle foams. (Reference: Memo from P. B. Rand and B. G. Hance to R. L. Woodfin dated February 29, 1996, in Appendix B)

Conclusions:

The intumescent foam formulation used, General Plastics FRLI-3702, did not prove satisfactory for the obstacle breaching application because of the poor mechanical properties produced when set up in water was required. This type foam may have other military uses, however.

Task Order:

Determine the effect of component and water temperatures on initial rise and tack free time. Evaluate the effect of density on compressive strength of foam. Test 2, 4, 6 pcf foams. Determine the effect of cure time on mechanical strength. T = 5, 10, 30, 60 minutes, and 24 hr.

Actual Experiments:

In this series of experiments, the components were heated or cooled in an environmental chamber to 40°, 60°. and 80° F. The conditioned components were then mixed and poured at ambient temperature, as described in 1.1.2.1.

In studying water performance, the intumescent foam's liquid components were poured into water and allowed to foam, as previously described for the standard foam (1.1.2.1).

Suitability 1.1

Mechanical 1.1.3

Strength 1.1.3.1

Introduction:

To allow better engineering models of the foams selected for use to form barriers over obstacles, we evaluated the mechanical properties of selected foams, particularly with regard to their strength. Both an intumescent foam and our preferred standard polyurethane foam were evaluated. Compressive strength properties were determined as a function of foam density, temperature, and time after the foam was formed.

Results:

The compressive strength of rigid polyurethane foams increases rapidly with increasing density; however, failure mechanisms in the experiments done with a 2-inch diameter ram were complex, involving tensile failure of the skin, compression, shear, and tearing of the foam. There is also some evidence that the mechanism of failure was different in the early time tests. The intumescent foam exhibited these typical properties as well. (Reference: Memo from P. B. Rand and B. G. Hance to R. L. Woodfin dated March 15, 1996, in Appendix B)

Conclusions:

The mechanical strength has been characterized adequately to enable needed analyses. These data will be used to assist in planning field experiments. They give a preliminary indication that strength develops rapidly enough to permit the initial passage of LCACs, followed by AAVs without delay, after the foam has been deployed.

Task Order:

Evaluate the effect of density on compressive strength of foam. Test 2, 4, & 6 pcf foams. Evaluate the effects of temperature on the compressive strength of foam. Maximum test temperature = exotherm temperature. Determine the effect of cure time on mechanical strength. (Develop bucket penetration test) Use T = 5, 10, 30, 60 minutes, and 24 hr.

Actual Experiments:

To allow the selection of the best density for this application, data were obtained at three density levels. Specimens for the evaluation of varying density on the compressive properties were cut from 8 x 8 x 3.2 inch molded foam blocks. All specimens were tested with the rise axis parallel to the test axis. Compressive stress data at 10%, 30%, and 50% strain versus density were studied.

We developed a simple test technique to evaluate a mechanical property at various times after foam formation. The test was done by penetrating the foam, formed in a cardboard tub, with a 2-in diameter ram. Both force and displacement were measured. The ram was allowed to penetrate 5 inches into the foam. Figure 49 plots penetration force curves for 5 minutes to 24 hours cure time. The knee in this cure time curve appears to be at 30 to 40 minutes. Further detail is provided in Appendix B.

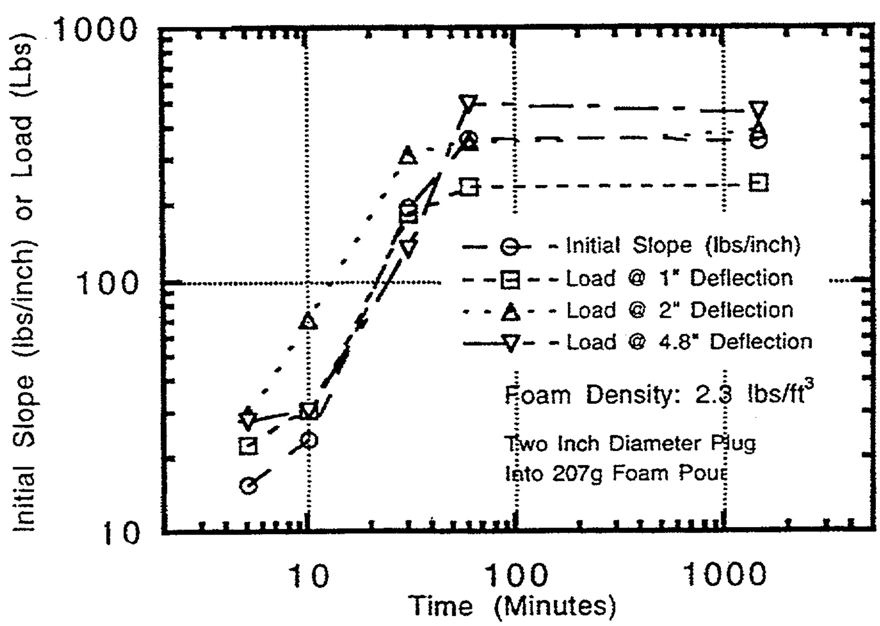

Figure 49. Plug Penetration of Foam vs Time after Foam Formation

Mechanical Suitability 1.1.3

Trafficability 1.1.3.2

Small Scale (Lab) 1.1.3.2.1

Application analysis and scale model experiments on 2 pcf foam were accomplished by R. J. Kipp and C. T. Coffin of Sandia 2522 in the Spring of 1995. The results of this initial assessment were briefed at the Sea Mine Countermeasure Project TCG meeting of April 13, 1995. These results formed the initial data for planning the full-scale experiments of Section 1.1.3.2.2.

Results: In the laboratory experiments, the foam survived repeated traverses by wheeled scale models as shown in Figure 50 with little permanent deformation. Testing with scaled AAV track loads as shown in Figure 51 left slight deformities in the foam.

Conclusions: Foam in densities of 2½ to 3½ pcf appeared to have the requisite strength properties for an assault ramp. The data from this initial analysis were used to specify the foam blocks ordered from Allied Signal.

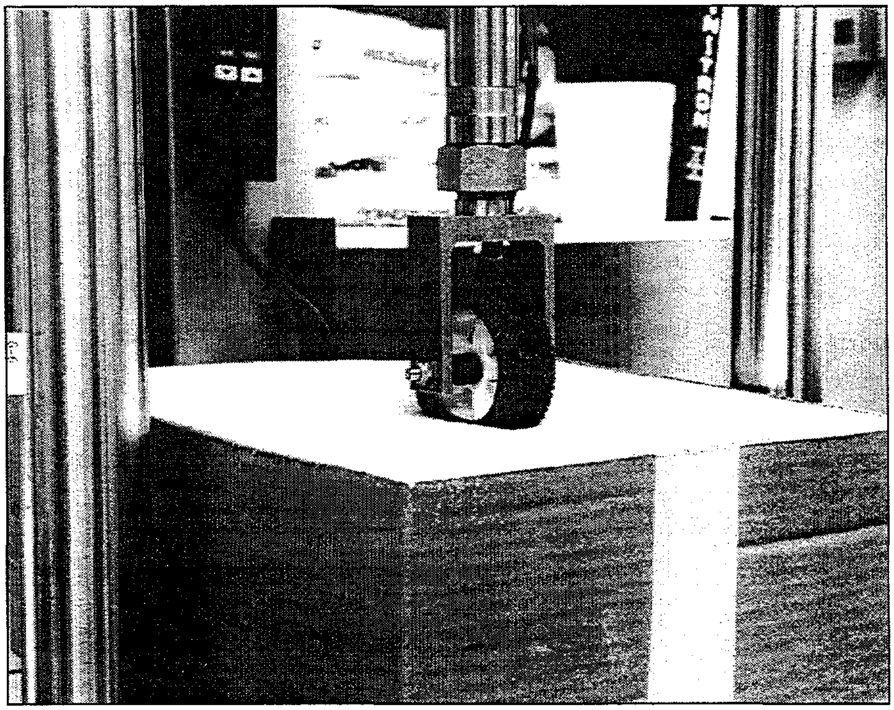

Figure 50. Scale Model Wheeled Vehicle Foam Testing

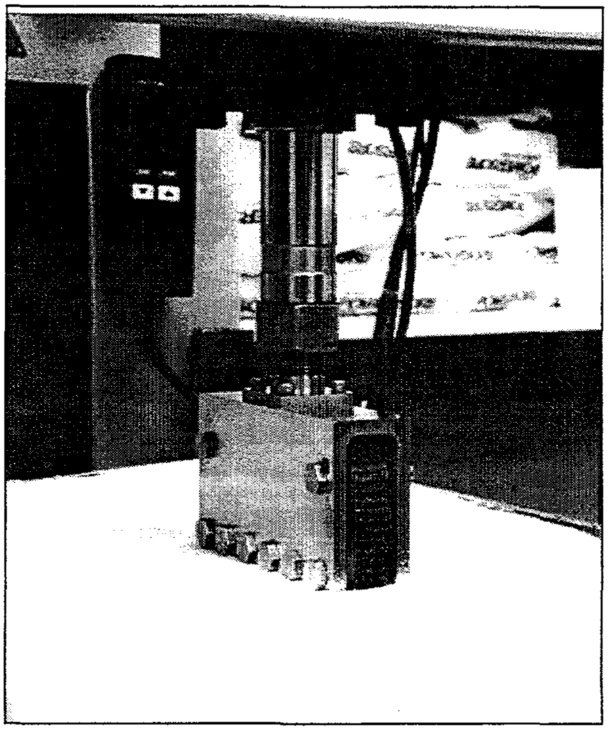

Figure 51. Scaled Track Foam Testing

Structural strength, flexural response, compressive and shear response, and local compressive loadings were calculated or modeled. In all cases, the 2 pcf foam appeared to be capable of withstanding the stress of supporting combat vehicles in an assault operation. Mr. Kipp's briefing is summarized as follows:

Sandia National Laboratories

Foam Applications Analysis & Scale Model Tests

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Sandia National Laboratories

Foam Applications Analysis & Scale Model Tests

- Initial Scoping Study for Structural Integrity - issues addressed
  - Self-supporting strength
  - Overall flexural response to "point load" from vehicles
  - Regional compressive & shear response to vehicles
  - Local response to compressive load from wheels & tracks
- Assumptions / Properties
  - Rigid urethane foam in 1-2 pcf range, isotropic
  - Homogenous "single big block", nominally 150' x 300' x 6'
  - Nominal properties for fully cured at room temperature
  - No reinforcement, mild elastic foundation

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Foam Applications Analysis & Scale Model Tests

- Preliminary Results:
  - Self-supporting strength
    - ✓ OK (> 130' simply supported span)
  - Overall flexural response to "point load" from vehicles
    - Marginally high stresses for ~2 pcf foam
    - → Reinforcement (necessary for operation anyway)
    - → Increase thickness, density (to ~3-4 pcf)
  - Regional compressive & shear response to vehicles
    - ✓ OK
  - Local response to load from tires & tracks
    - ✓ Subsequent slides

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Foam Applications Analysis & Scale Model Tests

- Preliminary Results for load from tires & tracks
  - Foam survives repeated traverses by tires with no perm. deformation in the 20-30 psi footprint load range, BUT
    - "Skin" appears significant (& doesn't scale)
    - Realistic tire footprint loads not attained
  - Foam shows slight track imprint from repeated AAV-level track loads
  - M1 tank-level track loads cause significant deformation & creep

- Potential Ways to Address tire & track load issues
  - Modest increase in foam density
  - "Layered" foam application
  - Fabric (Kevlar, etc.) or other flexible mat

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Foam Applications Analysis & Scale Model Tests

- Near-term Follow-on Work:
  - Scale-up wheel & track tests & include traction
  - FE analysis on load phenomena & include foam anisotropy

- Additional near-term structural issues:
  - Entry & exit vehicle loads
  - Anchorage, current, & wind loads
  - Cyclic loads & resultant fatigue
  - Strength vs. curing time / temperature relationships

Mechanical Suitability 1.1.3

Trafficability 1.1.3.2

Full Scale (Field) 1.1.3.2.2

Introduction:

In order to give the foam a credible test of how well it would be able to carry traffic loads from AAVs and other military vehicles, we conducted a rigorous series of trafficability experiments in the field. We wanted to study the amount of wear both 2 and 4 pcf blocks would experience when they were driven over repeatedly by vehicles of different types and weights.

To prepare for these experiments, a block of foam was placed in a wooden fixture, which was set into the ground so that the top surface of the foam was even with ground level. The top of each block was carefully measured prior to each experiment in order to set a baseline for determining wear later. Sand was compacted to form a comparable level of stiffness to the foam, so that the support on either side of the block and the support of the block itself were equal. To measure this stiffness, a device developed by Sandia for this purpose, a drop weight cylindrical penetrometer, was used. The penetrometer consisted of a pole formed from two-inch zinc iron pipe, approximately 5 ft high. Three 17 lb disks, which slide on the pole, are lifted up the pole exactly one ft and are then released, falling onto a ledge built into the pole. This impact drove the pole into the dirt and the penetration distance into the dirt was measured. A description and discussion of the penetrometer are in Appendix C.

In conducting these experiments, we used a 53 ton M60 tank and a 27 ton M110 howitzer, both with and without road pads, a standard military 6 x 6 truck fitted with rubber tires and carrying two 5,000 lb calibrated weights, and a small firetruck that weighed about 3.5 tons. The rubber road pads were removed from one track of each tracked vehicle in order to gather data with and without bare tracks. The trucks were run only at one speed; the tanks at two (slow and the maximum speed permitted by the distance available for acceleration, which was 14 mph for the M60 and 17 mph for the M110). As many as 32 passes were made over the block with the tracked vehicles and up to 105 passes with the trucks.

Footprint data for a variety of assault vehicles are shown in Figure 52.

Results: The results showed that the foam could withstand considerable traffic. Higher speeds produced more wear; however, most of the wear occurred in the first few passes. After these first passes, crushed foam particles developed which fell back into the rut and reduced the wear rate in subsequent passes. As expected, tanks with bare tracks caused more wear in the foam than did tanks with road pads or the military truck. Trucks caused less wear on the foam surface but appeared to throw crushed foam out of the ruts.

Conclusions:

From the data recorded using the four vehicles, the following statements can be made:

- Two pcf foam may be marginal for operational use with tracked vehicles such as the AAV-7 or AAAV.

- Four pcf foam is more than adequate from the standpoints of both wear and strength. A foam of 2½ to 3½ pcf may be optimum for this application. Further work will establish this more accurately.

Further experiments with foam that is partially or wholly supported on water are required.

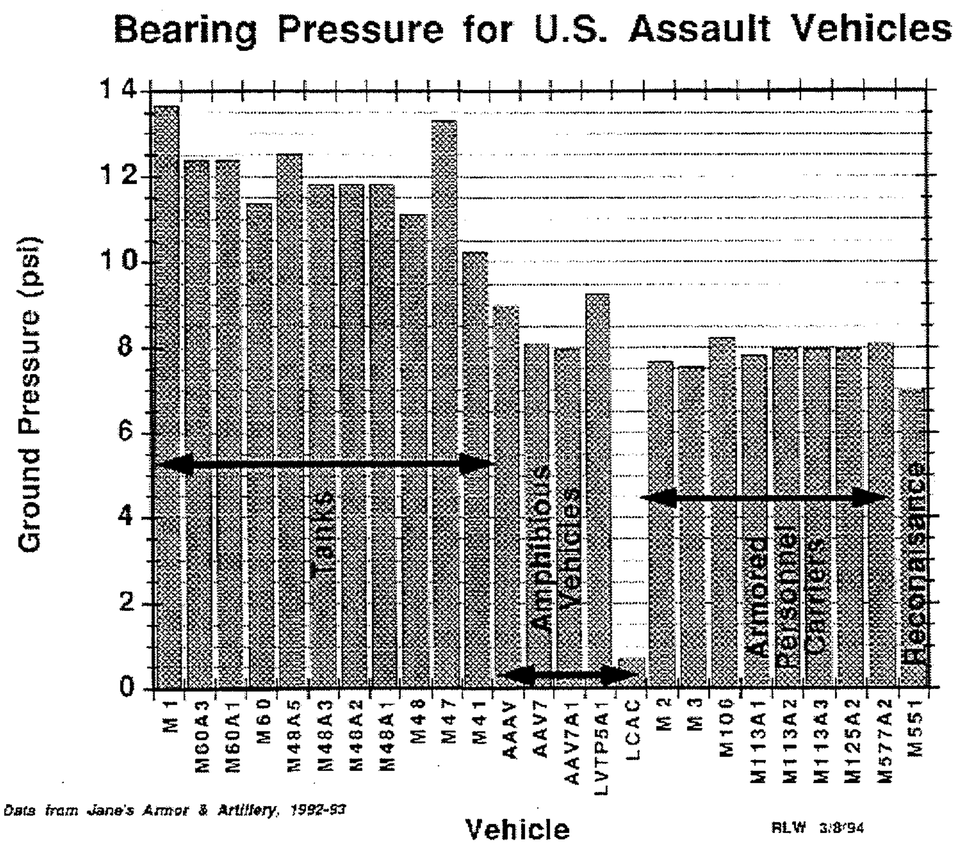


Figure 52. Bearing Pressures for Assault Vehicles

Task Order:

This will require feeling our way. We will start with sand surrounding the block buried to a depth which just exposes its surface. Surrounding soil compaction will need to be controlled to approximate the stiffness of the foam, so that the soil mimics the remainder of a large foam ramp. We will begin with the M110, with pads removed from one track and loaded to simulate the pressure of an AAV. We will use the 2 pcf blocks, followed by the 4 pcf blocks. We will begin with the track which has the pads ON. On the first pass, we will measure deflection while the vehicle is sitting on the block. We will then measure the residual deformation after the vehicle is moved off. We will then make a number of (~10 to 20) passes and measure the accumulated deformation at appropriate intervals. We will then do the same to another block with the pads OFF the track. After the tests with the M110, we will repeat with the M60, if that seems appropriate.

Actual Experiments:

Assumptions: A foam assault ramp will be driven over by LCACs (a number of times), by AAV-7s (at least 32 per lane), and possibly by tanks/recovery vehicles and wheeled vehicles before Combat Engineers can establish a cleared landing zone. The lighter LCAC pressure footprint was ignored in testing for the higher pressures of the tracked and wheeled vehicles.

Vehicles: M110 self-propelled howitzer at ~26.5 tons
M60A3 tank at ~53 tons
Mini fire truck at 3.5 tons
6 x 6, 5 ton cargo truck at 12 tons

Procedure: An area was selected on the EMRTC Main Pad with compaction characteristics approximating that of 2 and 4 pcf foam. A heavy plywood containment box was constructed below grade to partially contain the 54 x 54 x 54-inch foam blocks. Figure 53 is an overall view of the Main Pad experiment area, the vehicles involved, and the fixture. Baseline supports were inserted into the four corners of the containment box to provide a measuring plane 3 to 4 inches above the irregular top of the foam blocks.

Preparation: The foam block was inserted into the containment box by forklift. It was then backfilled with dry sand for the 2 pcf foam and dampened sand for the 4 pcf foam, compacted, and rolled to match the characteristics of the foam. Soil density was checked relative to the density of the foam with a drop weight cylindrical penetrometer and rolled/tamped until the penetration in the soil approximately matched the measured penetration of the foam. The foam block and soil were leveled and measurements were taken to the top of the "virgin" foam.

Operation: The vehicle was driven slowly over the compacted soil and the top of the foam block. After the specified number of passes, the experiment paused and measurements were taken across the top of the foam in a 9 x 9-inch grid pattern shown in Figure 54. Each time

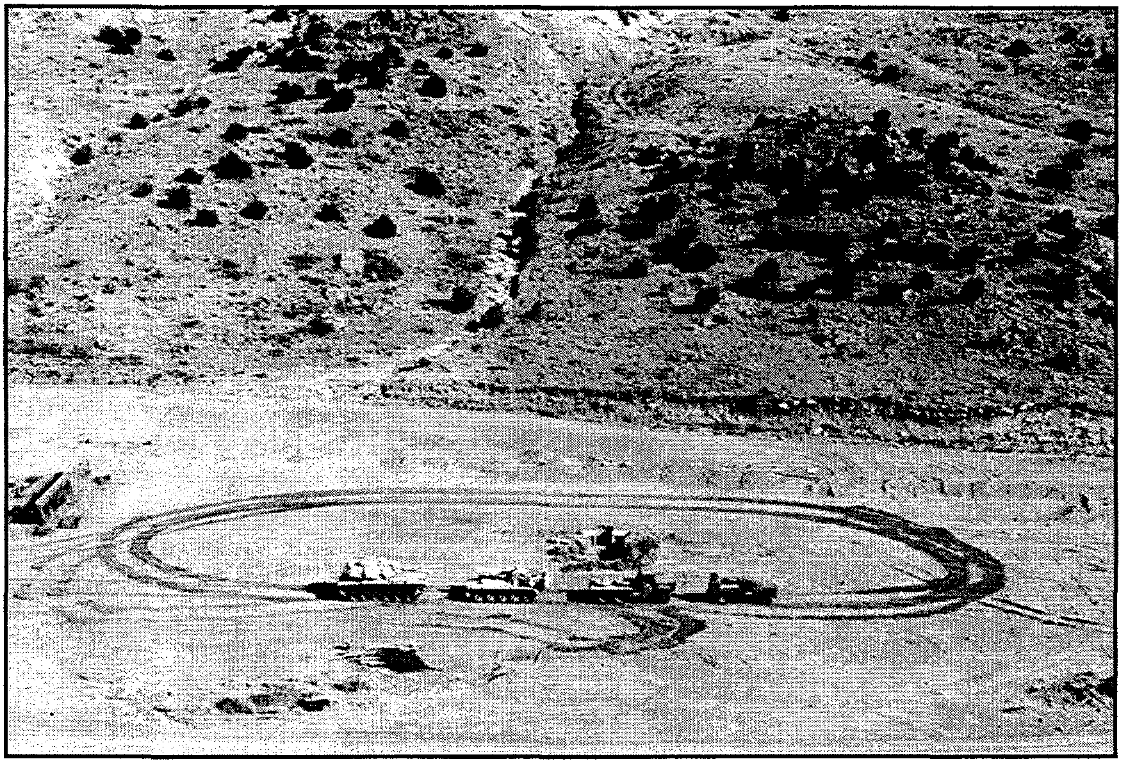


Figure 53. Overall View of Main Pad Experiment Area

the foam was measured, it was measured downward from the established base plane of the four corner baseline supports. The experiment was then continued, measuring at intervals, until the required number of passes had been made and measured or until a rut of depth sufficient to cause the underbelly of the vehicle to drag on the undisturbed foam (about 14 inches) developed. Photographic and video records were made before, during, and after the experiment.

In every experiment, the vehicle was maneuvered so as to make repeated passes in the same path. This was to produce maximum rut depth, hence a worst-case condition; this procedure was required by the small width of the blocks. In practice, one would expect vehicle paths to vary by a few feet and, hence, the rut depth produced by a specific number of passes to be less than that produced in the experiments. As the experiments progressed, it became apparent that the tamped sand on either side of the foam block was eroding and softening up more rapidly than the foam was worn down. This also would place more weight on the block than on the surrounding soil resulting in a worst-case condition.

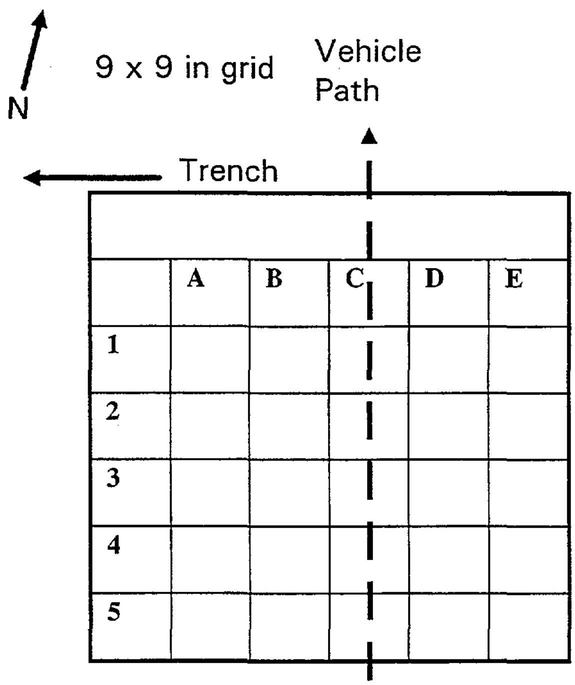


Figure 54. Measurement Grid Pattern for Trafficability Experiments

Variations: In order to obtain maximum data from the limited number of foam blocks, the experiment was interrupted, the block removed, and the upper portion was cut free. The short block was then replaced into the containment box with appropriate shoring to bring it back to grade level, soil moistened, tamped to specification, new tares recorded, and a new series of passes was begun.

Results: Table 1 shows measurements taken on 4 pcf foam after 32 passes of the M60 tank. (Also see Appendix D.)

In general: The 2 pcf foam was capable of supporting about 16 passes of the M110 gun at minimum speed. The 4 pcf foam withstood 32+ passes with any of the vehicles.

In conducting these experiments, the rubber road pads from one complete track of both the M60 and M110 were removed. During normal operational conditions, Marine Corps tracked vehicles would have all road pads removed to provide better traction. When traversing the foam, the track without pads caused a significantly higher wear rate on the foam. Figure 55 shows the M60 track with one road pad (center left) removed.

The 4 pcf foam withstood 32 passes of the M110 gun (with pads), 32 passes of the M60 tank (with pads), 32 passes of the M110 gun (without pads), and several passes of the mini fire truck, all at minimum speeds. It also withstood 32 passes of the M110 gun and M60 tank at high speed (about 17 mph). Appendix D contains the measurement data. Figures 56 through 65 are a photographic record of the setup, conduct, and results of the field experiment.

Table 1
Sample Block Deformation in 4 pcf Foam by the M60 (in inches)

Profile Data, Block 4-6		M60 Bare, Low Speed						
12/8/95								
Before Test		0	9	18	27	36	45	54
	9	0	16	19	17.25	19.375	19.875	0
	18	0	18.5	18	16.5	18.5	20.75	0
	27	0	17.625	15.25	16.75	18.375	19.625	0
	36	0	18.5	15.75	16.875	19	18.375	0
	45	0	15.5	18.375	18.75	19.5	18.25	0
After 8 passes		0	9	18	27	36	45	54
	9	0	19.75	21.25	21	21.25	21.25	0
	18	0	19.625	21.5625	21.75	22.25	22.625	0
	27	0	20.5	22.25	22.75	20.5625	21.625	0
	36	0	20.25	21.75	22.5	21.75	20.25	0
	45	0	20	21.75	21.75	21	19.625	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	24.125	24.4375	24.5625	22.4375	21.25	0
	18	0	24.75	25.3125	25	23.75	22.875	0
	27	0	25.1875	25.5	25.25	23.875	21.75	0
	36	0	25.5	25.5	25.25	23.875	19.75	0
	45	0	25.25	24.75	24.5625	22.9375	19.5	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-3.75	-2.25	-3.75	-1.875	-1.375	0
Average Wear =	18	0	-1.125	-3.5625	-5.25	-3.75	-1.875	0
-3.59375	27	0	-2.875	-7	-6	-2.1875	-2	0
	36	0	-1.75	-6	-5.625	-2.75	-1.875	0
	45	0	-4.5	-3.375	-3	-1.5	-1.375	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	-8.125	-5.4375	-7.3125	-3.0625	-1.375	0
Average Wear =	18	0	-6.25	-7.3125	-8.5	-5.25	-2.125	0
-6.921875	27	0	-7.5625	-10.25	-8.5	-5.25	-2.125	0
	36	0	-7	-9.75	-8.375	-4.875	-1.375	0
	45	0	-9.75	-6.375	-5.8124	-3.4375	-1.25	0

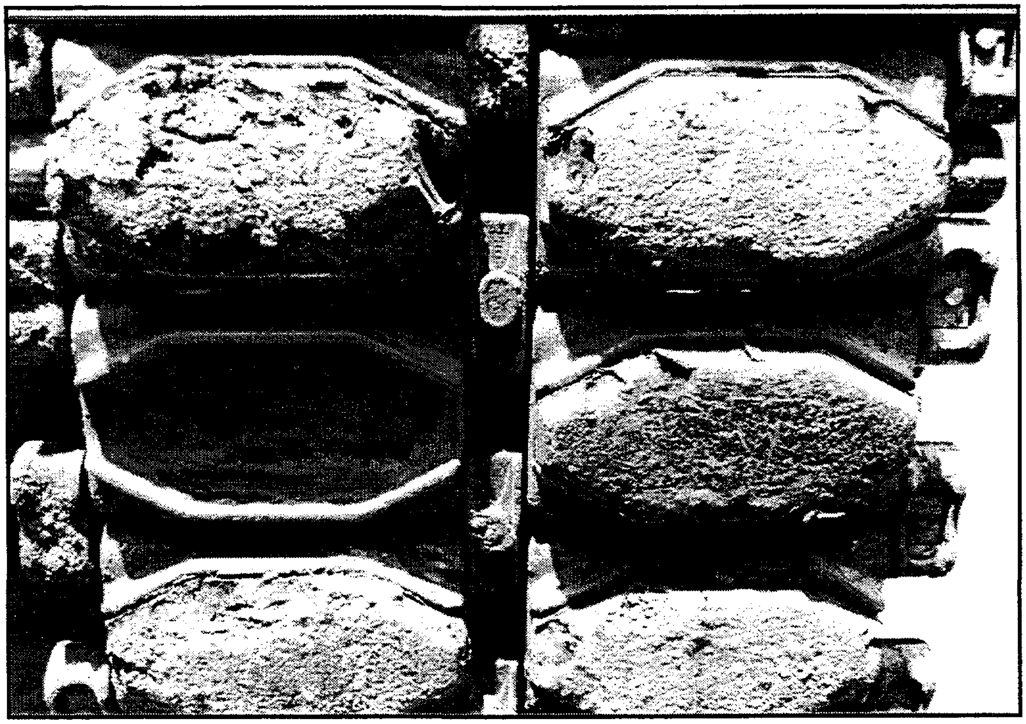


Figure 55. M60 Track with One Road Pad (center left) Removed

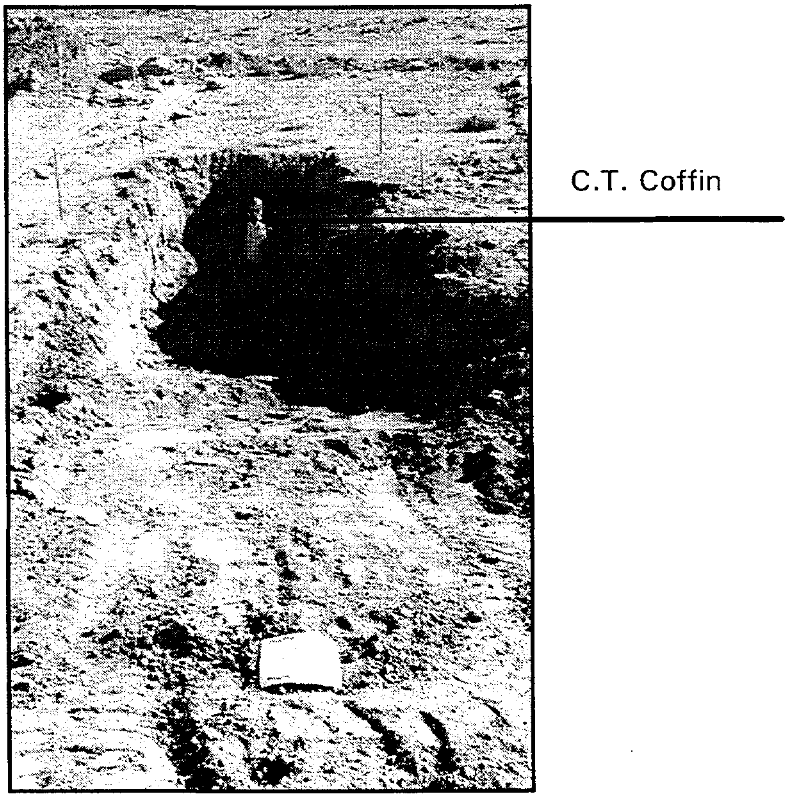


Figure 56. Excavation for Foam Block at Main Pad Area (C. T. Coffin is about 5' 8" tall for comparison)

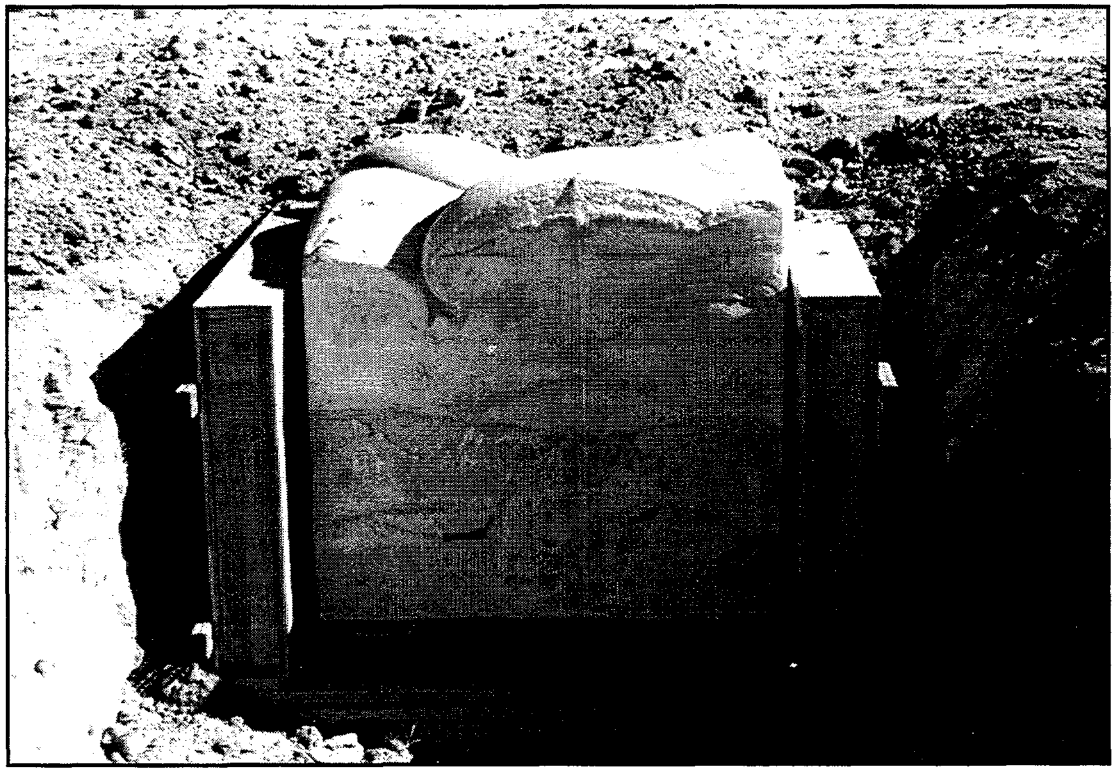


Figure 57. Foam Block Inserted into Experiment Fixture

Figure 58. Inspection during TCG Demonstration

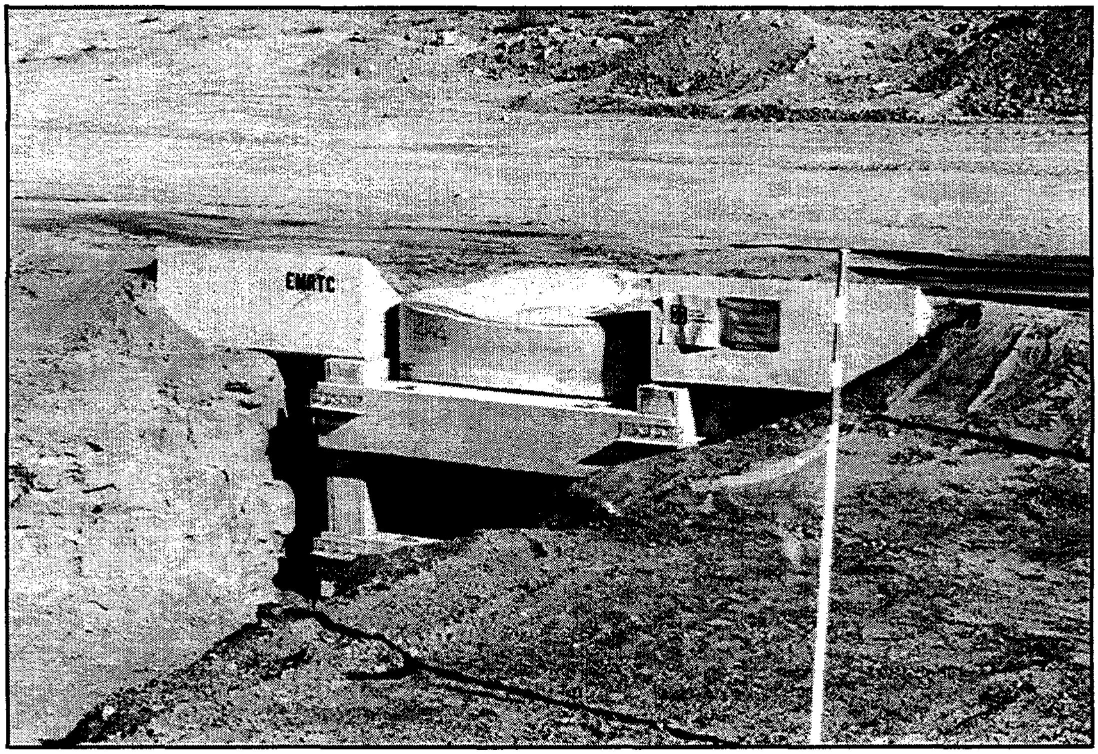


Figure 59. Foam Block Setup Complete (ready for experiment)

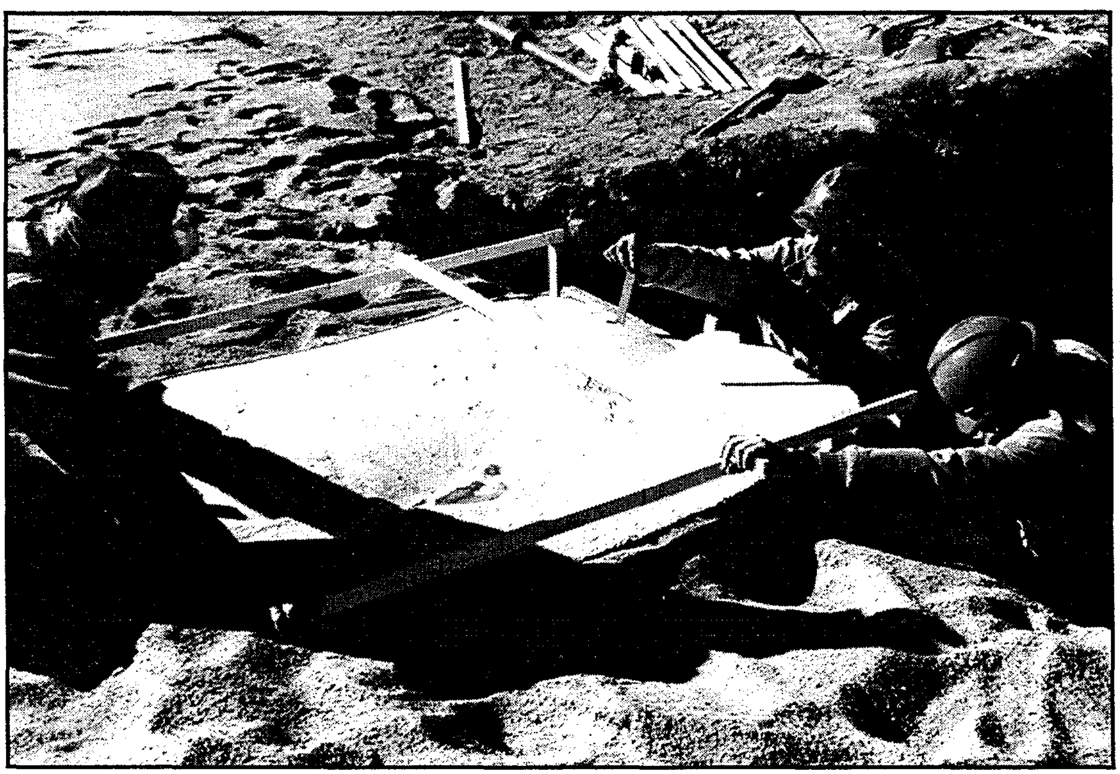


Figure 60. Taking the Initial (pre-experiment) Depth Measurements (tares)

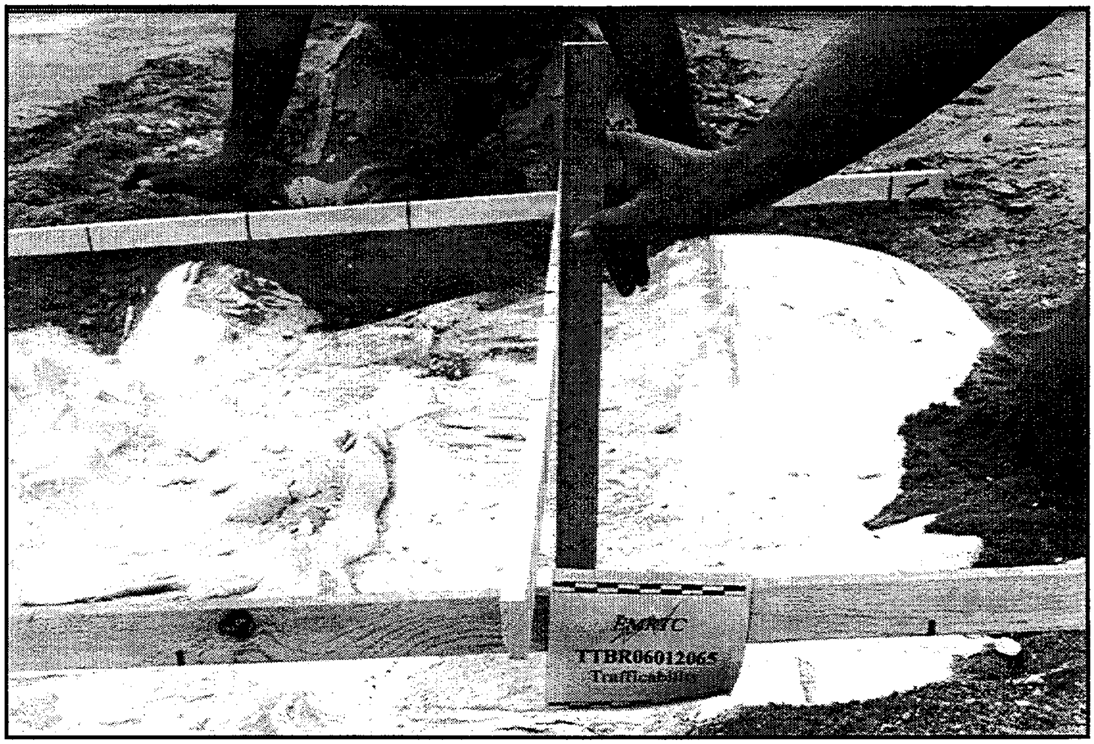


Figure 61. Taking Depth Measurements on Block #04-02

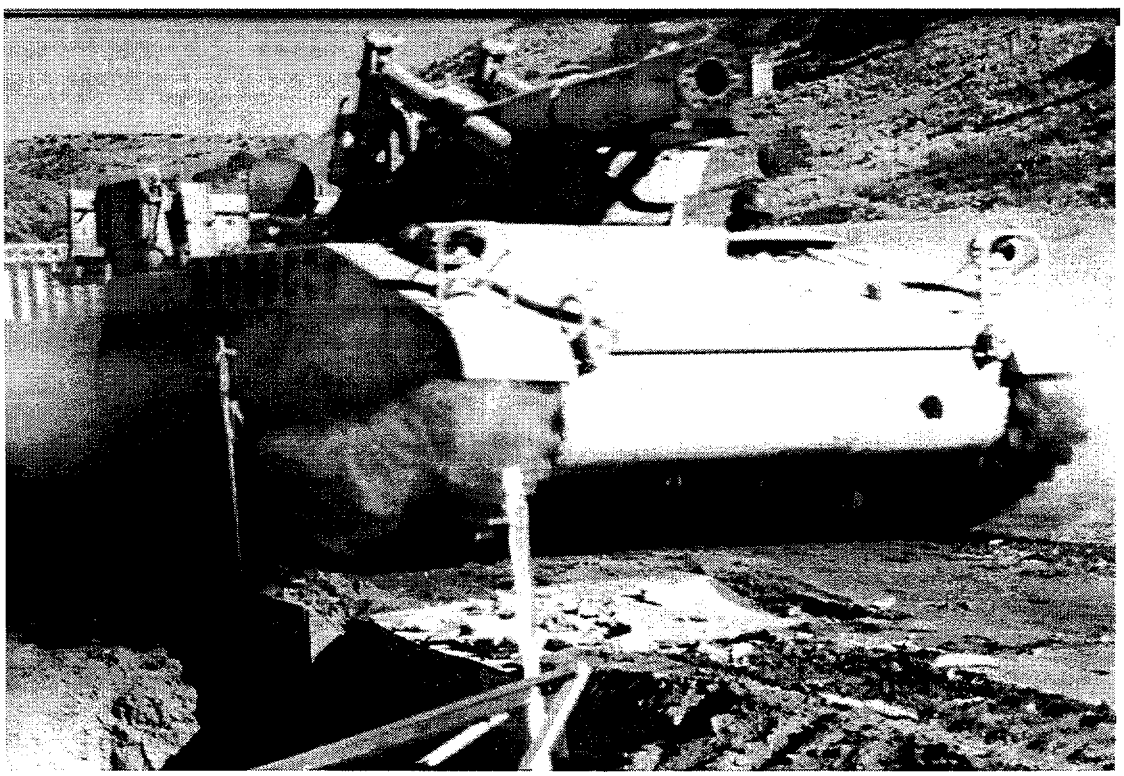


Figure 62. M110 Self-Propelled Howitzer (in a high-speed run over 4 pcf foam during the demonstration for the TCG)

Figure 63. M60 Tank in a High-Speed Run over 4 pcf Foam (the right-hand track relative to the driver, left in photo, has road pads; left-hand track is "bare")

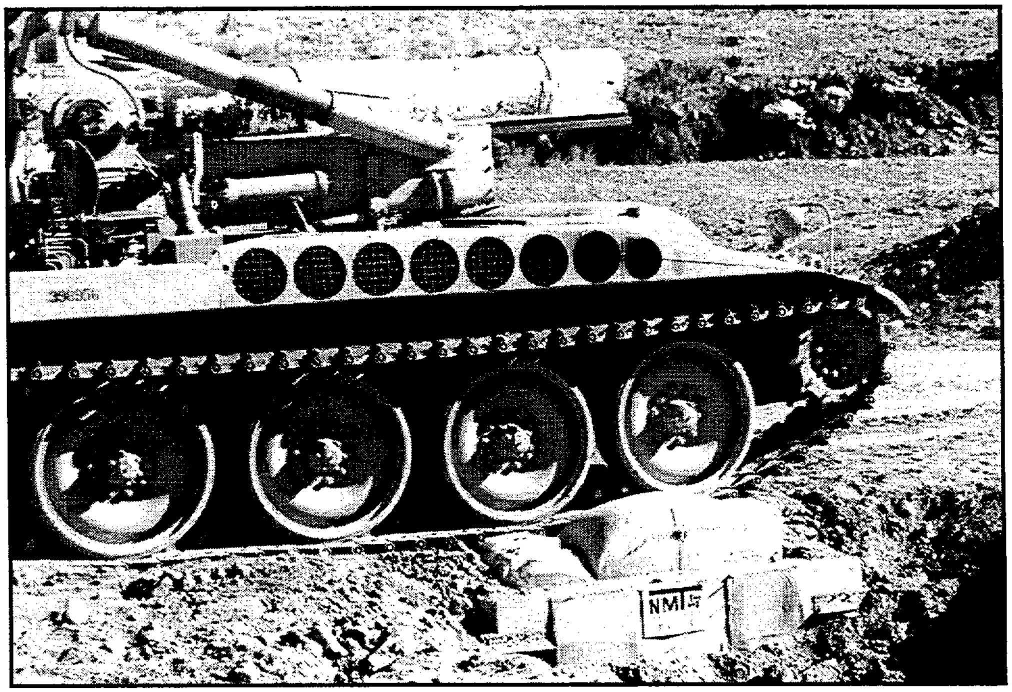


Figure 64. M110 on First Pass over 2 pcf Foam

Figure 65. Block #02-02 after 8 Passes by M110 (pads on at low speed, rut swept clean)

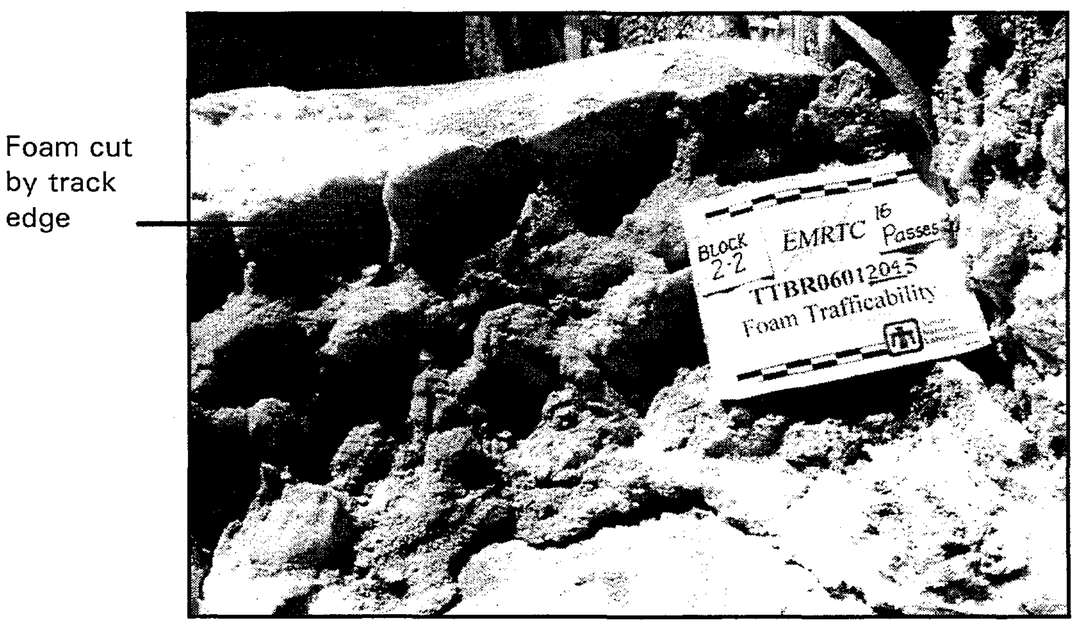


Figure 66. Block #02-02 After 16 Passes by M110 (pads on at low speed)

This was about the limit for the 2 pcf foam. After 16 passes with the M110, ruts of 14 to 15 inches were recorded and the vehicle was bottoming out on the higher areas of the foam.

Six different 2 pcf foam blocks were tested using both the M110 howitzer and the M60. Vehicle tracks were run both with and without the rubber road pads. Figure 66 shows the data recorded for both the 2 and 4 pcf experiments. Measurements of the rut depth were taken as indicated for each block. Appendix D contains the raw measurement data and a variety of graphic plots.

The 2 pcf foam developed ruts rapidly when traversed by either tracked vehicle. Tracks without road pads (bare) eroded the foam slightly faster than with the pads installed. After breaking the surface of the foam initially, the sides of the vehicle tracks, outside the pad area, seemed to cause most of the erosion. This created a smaller than anticipated difference between pads on and pads off wear. The more thickly padded M60 tracks wore less than the lighter M110. The M110 track design is considerably more aggressive than that of the M60. Figures 67 through 70 show the conduct and results of the experiment.

Summary of Data from Trafficability Experiments on Polyurethane Foam Blocks													
											Sheet	Date	Block #
No. Passes	**0**	**4**	**8**	**12**	**16**	**20**	**23**	**32**	**64**	**96**			
2pcf M110 Pads, Slow	0.0	-5.7	-7.5	-13.2	-14.8						**3**	12/4/95	2-2
2pcf M110, Pads, Fast	0.0		-12.4								**11**	12/19/95	2-6
2pcf M110 Bare, Slow	0.0	-6.0	-10.1								**2**	11/30/95	2-1
2pcf M110 Bare, Fast	0.0		-13.1								**12**	12/20/95	2-7
2pcf M60, Bare, Slow	0.0		-7.9	-9.7							**13**	12/19/95	2-4
2pcf M60, Pads, Slow	0.0		-6.6	-8.5							**14**	12/19/95	2-5
4pcf M110 Pads, Slow	0.0	-0.8	-1.5			-2.2		-3.2			**4**	12/5/95	4-1
4pcf M110 Bare, Slow	0.0	-2.2	-3.2			-5.6		-7.4			**6**	12/7/95	4-3A
4pcf M110 Pads, Fast	0.0		-3.0				-8.2	-10.9			**7**	12/8/95	4-3B
4pcf M60, Pads, Slow	0.0	-0.8	-1.2			-1.7		-2.3			**5**	12/6/95	4-2
4pcf M60, Pads, Fast	0.0		-1.7					-3.5			**8**	12/8/95	4-4
4pcf M60, Bare, Slow	0.0		-3.6					-6.9			**9**	12/8/95	4-6
4pcf M60, Bare, Fast	0.0		-1.8					-4.6			**10**	12/19/95	4-7
4pcf 6x6 Truck 23K#	0.0							-2.5	-6.1	-12	**15**	1/16/96	4-8
6pcf 6x6 Truck 23K#	0.0							-0.4	-1.3	-3.6	**16**	2/21/96	

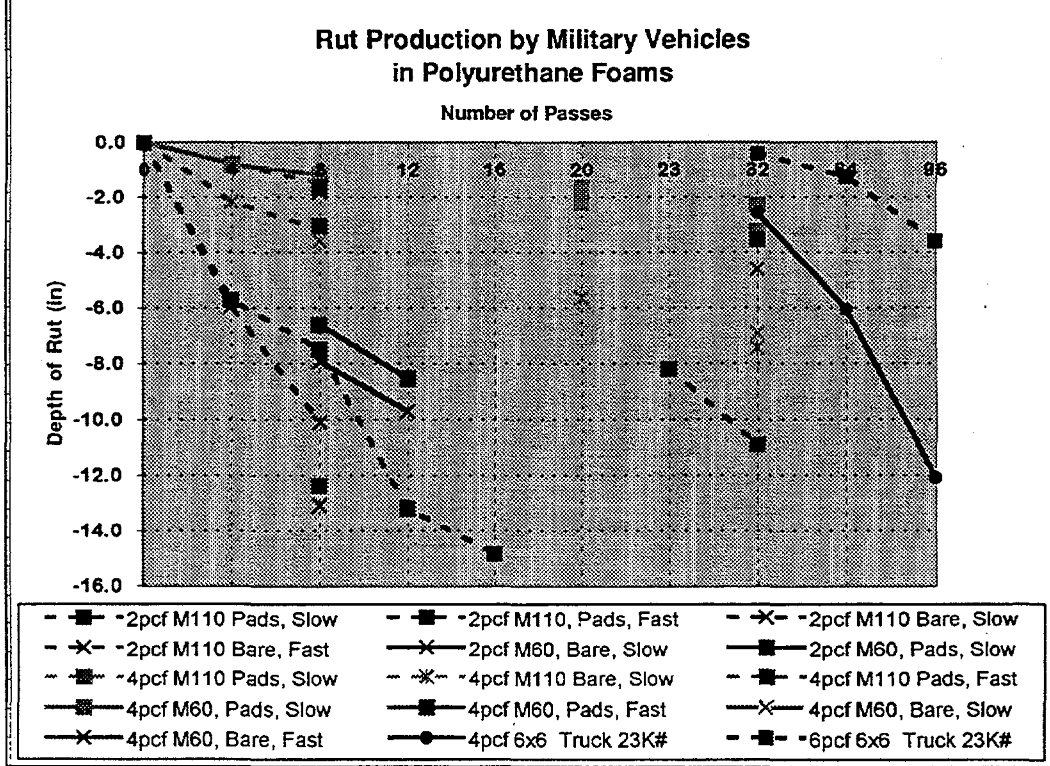


Figure 67. Summary of Rut Data in 2 and 4 pcf Foam

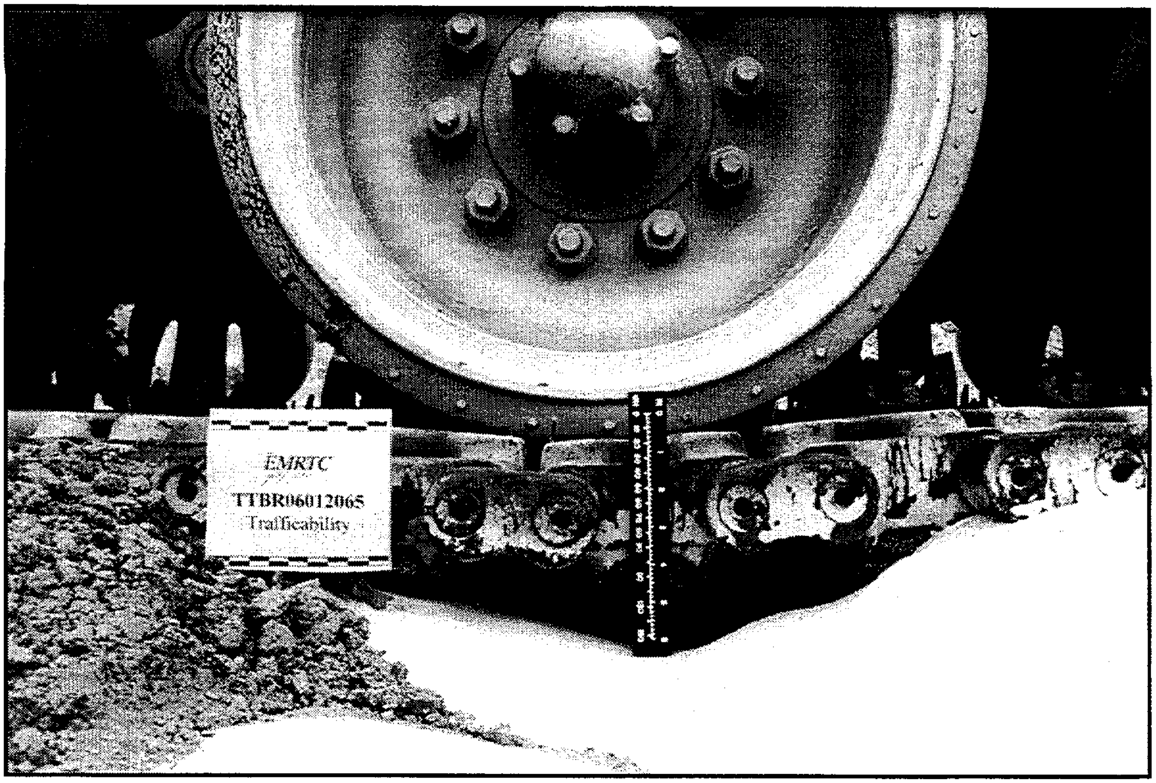


Figure 68. M110 "Bridging" on 4 pcf Foam (clearance is about 1½ inches)

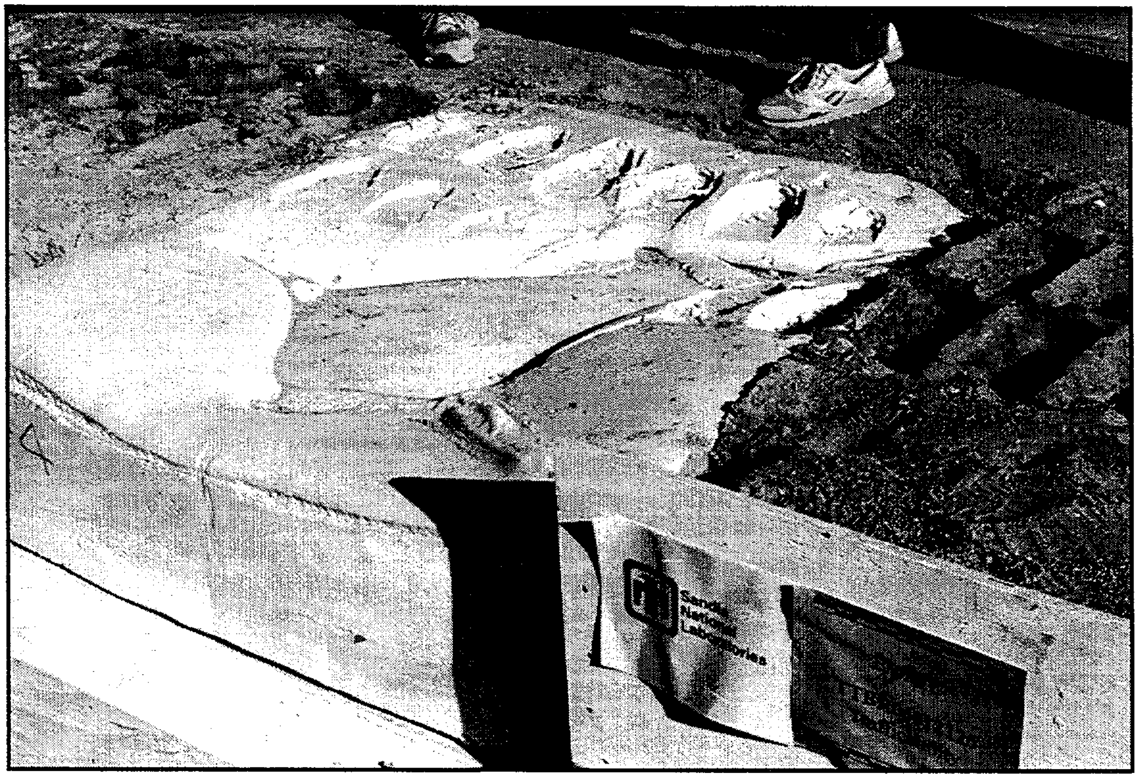


Figure 69. Block #04-04 after Single Pass by M60

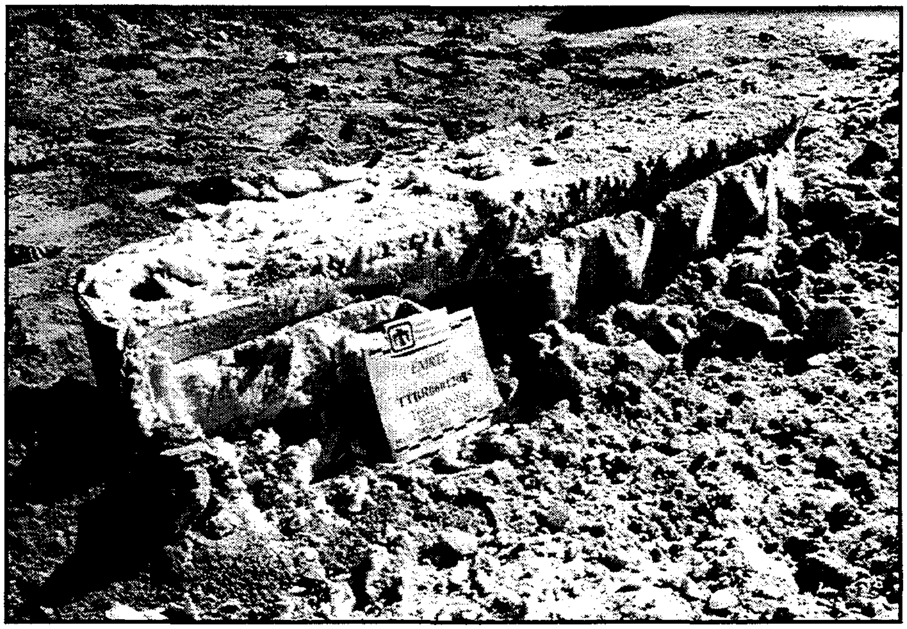


Figure 70. Block #04-03 after 32 Passes by M110 (pads on at high speed)

In order to complete the data set, experiments were conducted using a 3.5 ton miniature fire truck on a 3/4 ton pickup body, shown in Figure 71, and a 5 ton 6 x 6 cargo truck, shown in Figure 72. Because of the much smaller footprint, ground pressures for wheeled vehicles are typically several times higher than those for tracked vehicles. For example, the 3.5 ton fire truck exerted about 23 (front) and 35 psi (rear) ground pressure compared to 11½ psi for the 53 ton M60.

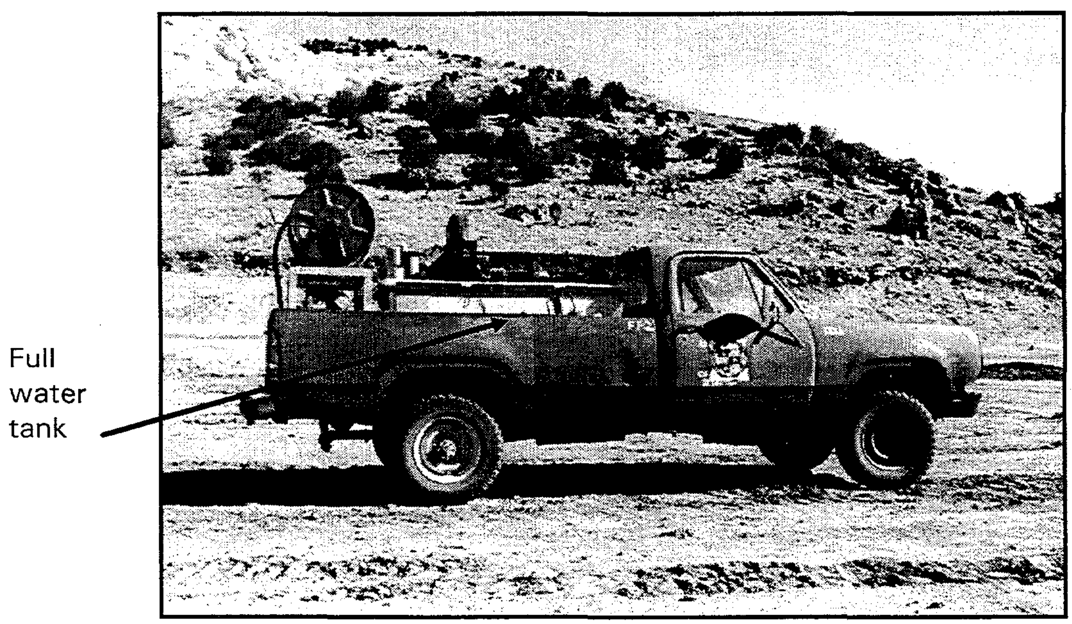


Figure 71. Mini Fire Truck (3.5 tons)

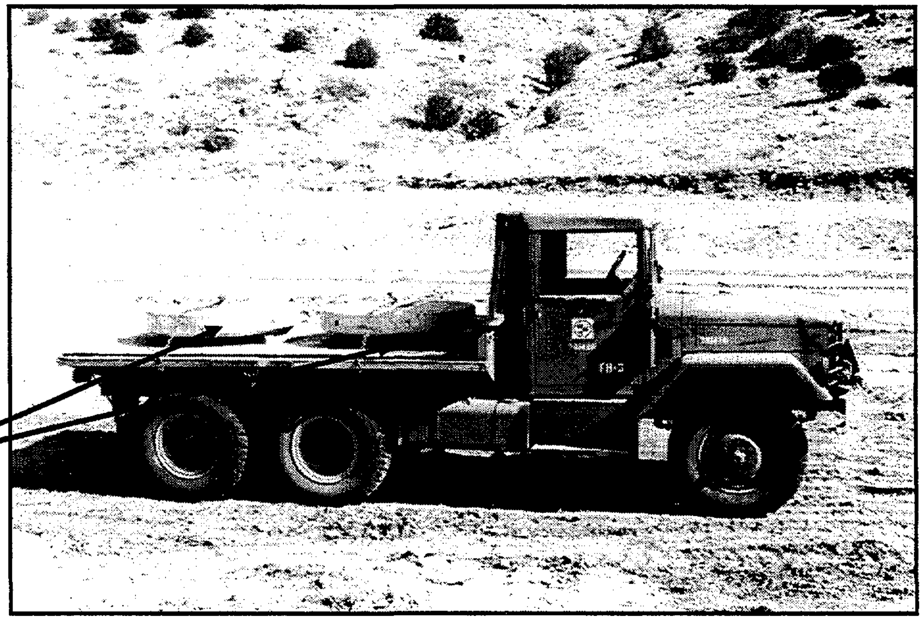


Figure 72. 5 Ton Cargo Truck Loaded with Test Weights

In testing the mini fire truck on 4 pcf foam, no marks could be seen in the foam after several slow passes. The truck drove over a piece of scrap foam roughly 4 x 4 ft and only ½ inch thick. The rear tire did leave a compacted impression in the foam with a maximum depth of 1/8 to 3/16 inch.

The 5 ton cargo truck was loaded with five tons of weights and driven over a 4 pcf block. After 32 passes, the rut was 2.55 inches (average) deep. The rut depth increased to 6.05 inches at 64 passes and 12.08 inches after 96 passes.

In February 1996, the 5 ton 6 x 6 was driven at moderate speed (20 mph) over a 6 pcf foam block to see if the denser foam might be suitable for temporary road repairs. After 96 passes at high speed with a full load of 10,000 lb, only about 3½ inches of wear was observed. This experiment began after the M60 had been driven over the block several times for a demonstration, so it probably represented worst-case wear. After 105 passes, the truck suffered a major cooling system casualty and the experiment was abandoned.

Figure 73 shows that the 2 pcf foam eroded about four times as fast as the 4 pcf foam. The 2 pcf foam may be marginal for operational use with AAVs. In Figure 73, note that the wear curves for tracked vehicles and those with rubber tires show very different trends. This may be due, at least in part, to the conditions of the experiment. As the tracked vehicles made repeated passes, the debris (both foam particles and sand) accumulated in the rut providing some protection against further wear. When the wheeled vehicles made repeated passes, they tended to move the sand backfull away from the edges of the foam block. This caused progressive wear by breaking down the entry edge of the foam block. We anticipate that the results for wheeled vehicles might be somewhat different if the approach to the foam block were more rigid. We have designed another experiment (1.1.3.2.4) to examine this.

Figure 74 is a summary depiction of the data in Figure 73 of the different vehicles, configurations, and speeds that would produce in a 12-inch rut.

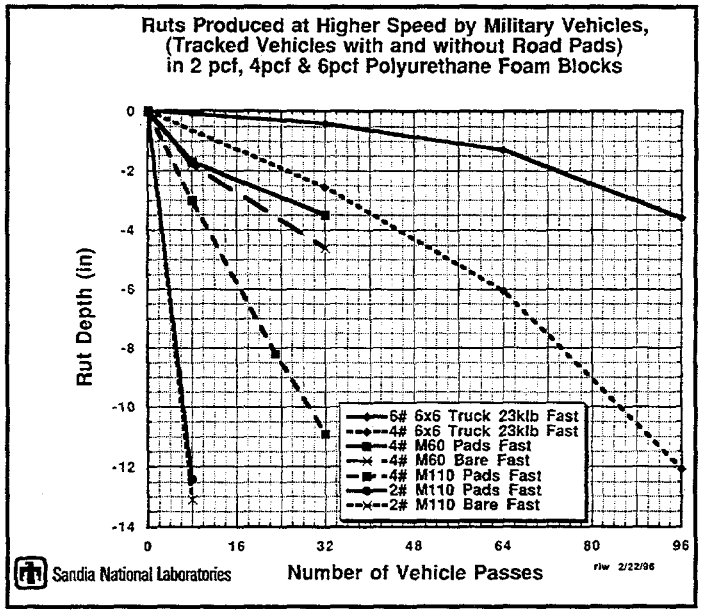


Figure 73. Plots of Rut Formation at Higher Speeds (The M60 was driven at about 14 mph and the M110 howitzer at 17 mph.)

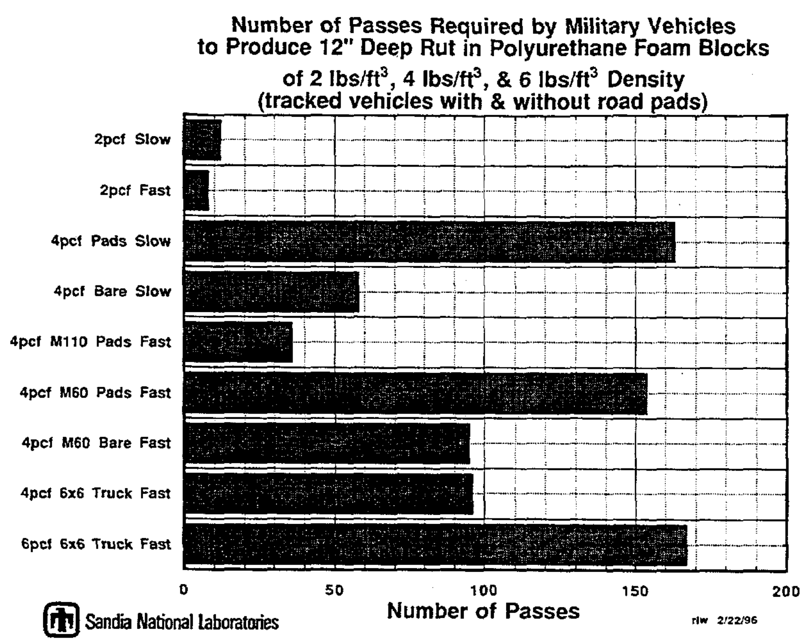
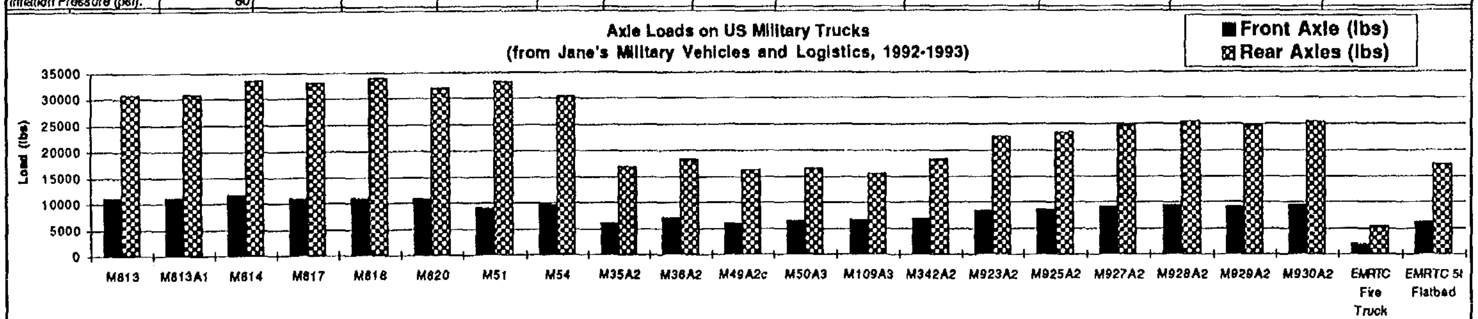


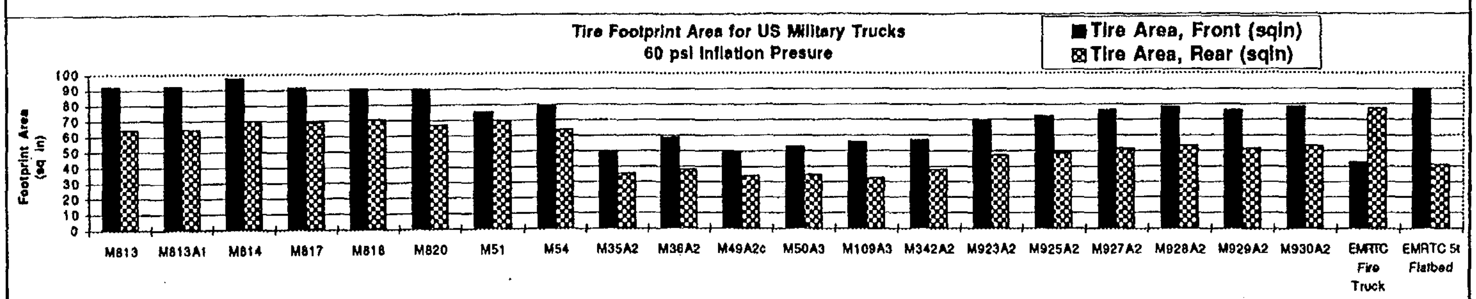
Figure 74. Extrapolation of Test Data (the number of passes needed to produce a 12-inch rut that was assumed as the depth that would begin to cause interference with vehicle undercarriage)

Figure 75 shows the footprints and loadings for representative military vehicles.

Loads and Areas of Military Truck Tires

Model	Jane's page #	Front Axle (kg)	Rear Axle (kg)	Front Axle (lbs)	Rear Axles (lbs)	Total (lbs)	Front Load %	Rear Load %	# Tires Loaded (rear)	Tire Area, Front (sqin)	Tire Area, Rear (sqin)	Ground Load, Front (psi)	Ground Load, Rear (psi)
M813	443	5015	13969	11033	30732	41765	26%	74%	8	91.94	64.02	60	60
M813A1	443	5016	13976	11035	30747	41782	26%	74%	8	91.96	64.06	60	60
M814	443	5326	15223	11717	33491	45208	26%	74%	8	97.64	69.77	60	60
M817	443	4981	15047	10958	33103	44062	25%	75%	8	91.32	68.97	60	60
M818	443	4950	15399	10890	33878	44768	24%	76%	8	90.75	70.58	60	60
M820	443	4936	14523	10859	31951	42810	25%	75%	8	90.49	66.56	60	60
M51	442	4112	15088	9046	33194	42240	21%	79%	8	75.39	69.15	60	60
M54	442	4347	13807	9563	30375	39939	24%	76%	8	79.70	63.28	60	60
M35A2	440	2700	7700	5940	16940	22880	26%	74%	8	49.50	35.29	60	60
M36A2	440	3200	8300	7040	18260	25300	28%	72%	8	58.67	38.04	60	60
M49A2c	440	2700	7400	5940	16280	22220	27%	73%	8	49.50	33.92	60	60
M50A3	440	2880	7528	6336	16562	22898	28%	72%	8	52.80	34.50	60	60
M109A3	440	3000	7100	6600	15620	22220	30%	70%	8	55.00	32.54	60	60
M342A2	440	3100	8300	6820	18260	25080	27%	73%	8	56.83	38.04	60	60
M923A2	445	3788	10242	8334	22532	30866	27%	73%	8	69.45	46.94	60	60
M925A2	445	3923	10606	8630	23334	31964	27%	73%	8	71.92	48.61	60	60
M927A2	445	4138	11189	9104	24615	33719	27%	73%	8	75.87	51.28	60	60
M928A2	445	4273	11553	9401	25417	34817	27%	73%	8	78.34	52.95	60	60
M929A2	445	4142	11198	9112	24636	33748	27%	73%	8	75.93	51.33	60	60
M930A2	445	4277	11563	9409	25439	34848	27%	73%	8	78.41	53.00	60	60
EMRTC Fire Truck		900	2500	1950	5380	7330	27%	73%	2	42.39	76.66	23	35
EMRTC 5t Flatbed		2900	7765	6100	17360	23460	26%	74%	8	89.71	40.94	34	53
Inflation Pressure (psi):		60											





Tire Loads RLW 2/26/96

Figure 75. Loads and Footprints of Wheeled Vehicles

Figure 76 shows the M60 tank putting most of its track pressure on the 6 pcf foam block. After several passes, the M60 tread prints were barely visible in 6 pcf foam

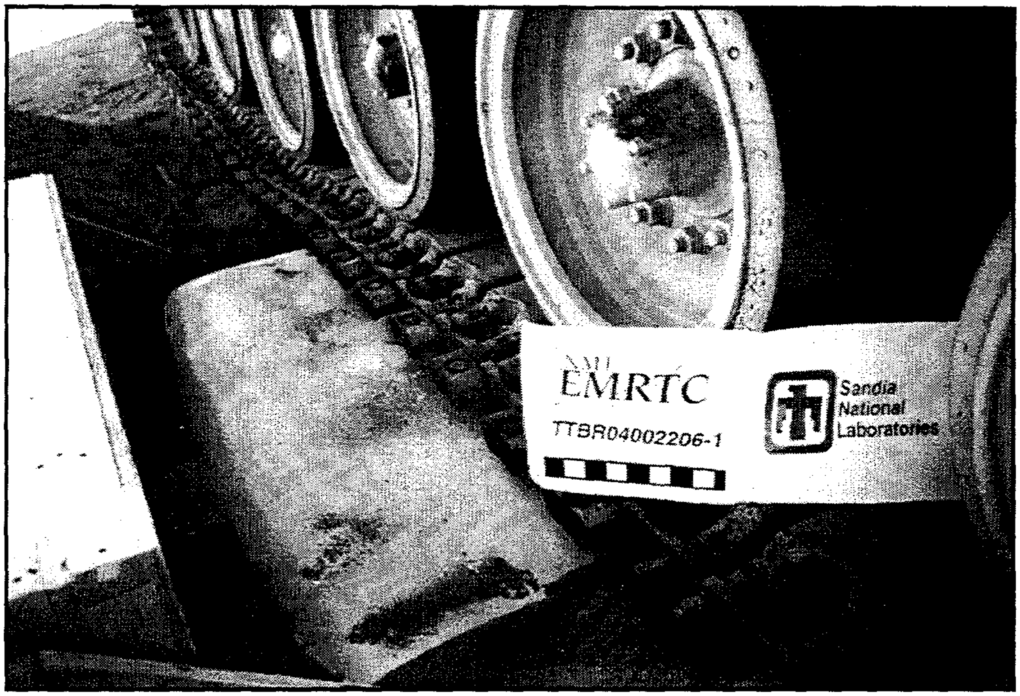


Figure 76. M60 on 6 pcf Foam

After about seven slow passes, the marks on the surface of the 6 pcf foam measured only about ½ inch depth as shown in Figure 77.

Figure 77. Rut in 6 pcf Foam (½ inch after several passes)

The wear experiment using EMRTC's 6 x 6 truck was done at moderate speeds of 15 to 20 mph. The deep lug military tires provided a footprint much higher in pressure than the tracks of the M110 and M60, but did considerably less damage per pass to the foam. Figure 79 shows the loaded 6 x 6 crossing the foam as it did for 105 passes.

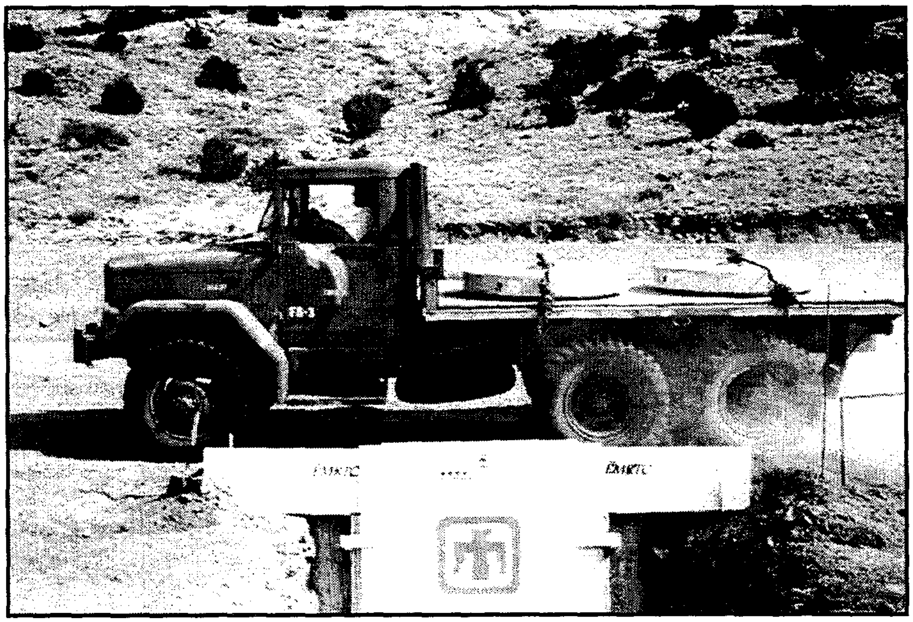


Figure 78. 5 Ton 6 x 6 on 6 pcf Foam (at moderate speed)

Figure 79 illustrates the width of the dual tires in relation to the M60 track marks and the deep lug military tires.

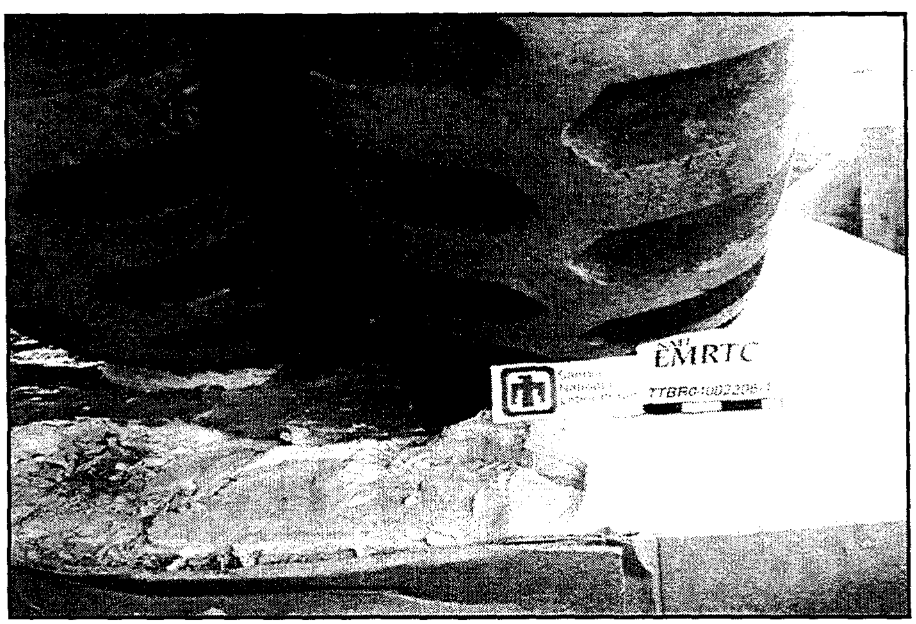


Figure 79. Rear Tires of 6 x 6 on First Pass (6 pcf foam)

The rut depth from the 6 x 6 truck was measured at 32, 64, and 96 passes. Total wear in the 6 pcf foam amounted to just over 3½ inches. Even with a ground load of 34 psi (front) and 53 psi (rear), this vehicle did much less damage to the foam. Figure 80 shows the rut after 105 passes.

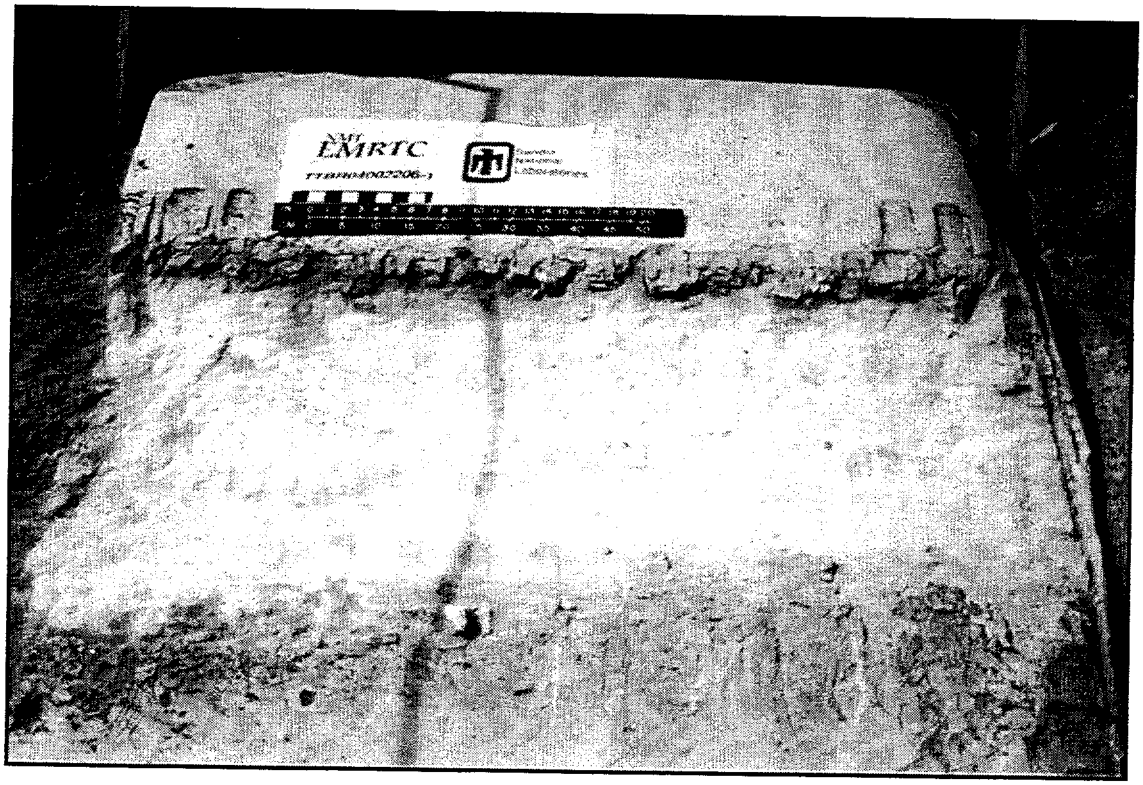


Figure 80. 6 pcf Foam Block after 105 Passes by 6 x 6 (rut depth about 3½ inches)

Mechanical Suitability 1.1.3

Trafficability 1.1.3.2

Road Repair - Preliminary 1.1.3.2.4

Introduction:

A follow-on experiment to determine the feasibility of using medium weight foam for road or runway repair was begun at EMRTC beginning in mid-March 1996.

Four 6 pcf foam blocks, approximately 12 x 12 x 18 inches, were buried in the roadway at EMRTC to see how they would withstand vehicle traffic over the long term. Two blocks were planted in reinforced concrete and the other two were encased in packed asphalt. All four blocks were seated about level with the road material.

Result: TBD.

Conclusions: TBD

Task Order:

Pick a spot with maximum traffic. Embed foam blocks in concrete and asphalt to simulate repaired potholes. Use both 4 and 6 pcf blocks approximately 1 ft square. Ensure local drivers understand they are to drive over the simulated patches each time they pass that point. Count the number of passes over each block. Measure and photograph the blocks on a regular basis based on either elapsed time or traffic counts. Call me periodically with results. I will visit to observe when appropriate.

Actual Experiment:

Two large holes were cut into the asphalt roadway at the junction of Blue Canyon Road and the turnoff to the Main Pad area. This roadway divides several times, going to three different experiment areas and carries the majority of the traffic on the EMRTC range. A traffic counter was borrowed and installed to record the actual traffic over the blocks.

Two blocks of 6 pcf foam were installed in each hole approximately level with the roadway. One set of blocks was backfilled with patching asphalt and tamped back to grade. The second set of blocks was encased in reinforced concrete and leveled to match the roadway. Figures 81 through 86 show the setup for this experiment.

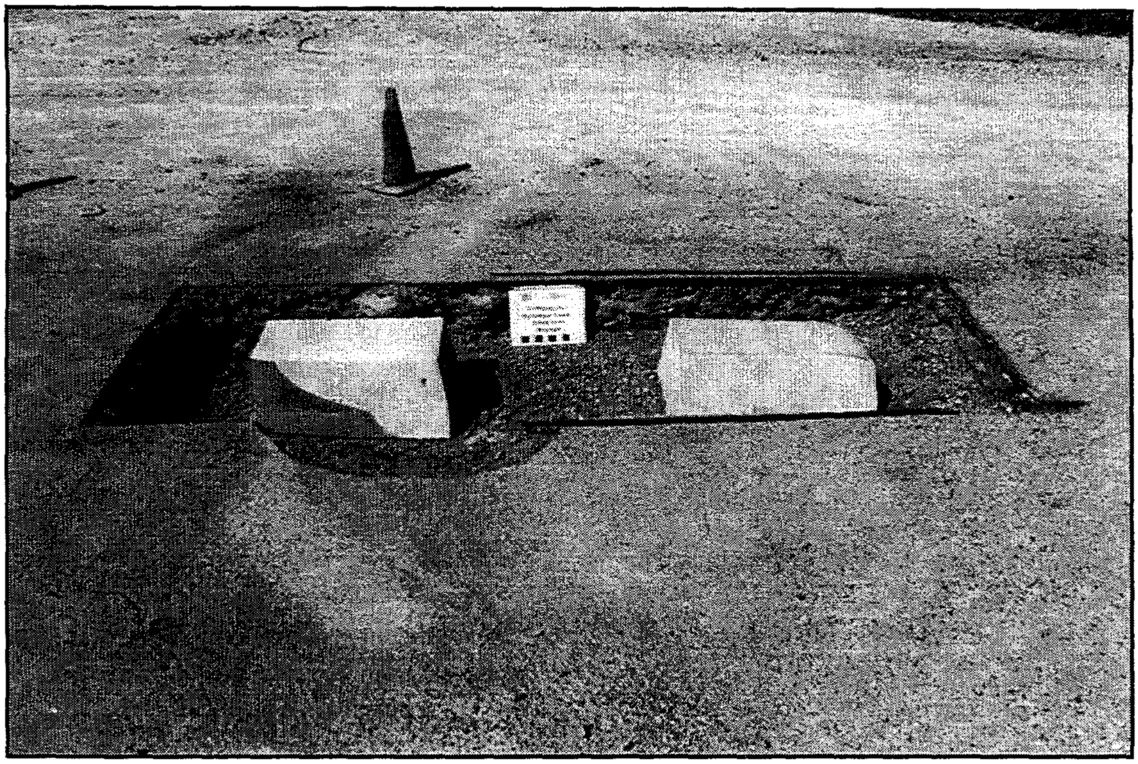


Figure 81. Hole for the Asphalt Road Experiment

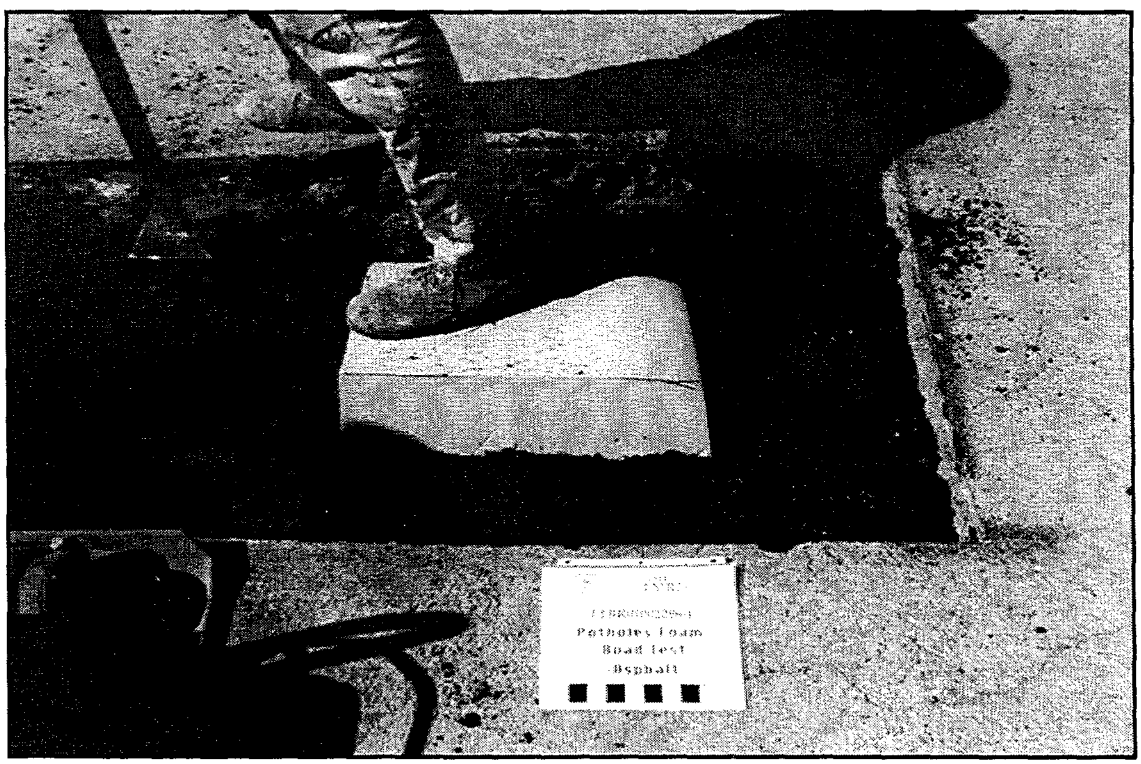


Figure 82. Backfilling the First Set of Blocks

Figure 83. Asphalt-Filled Road Experiment on Completion

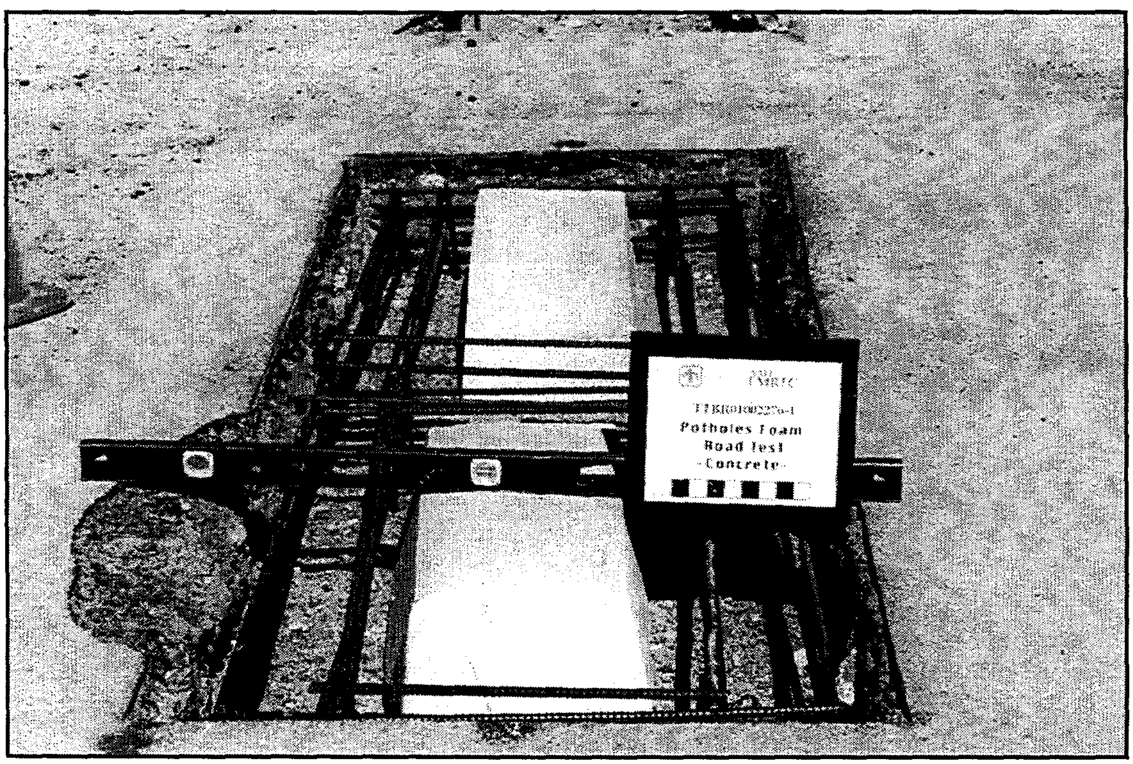


Figure 84. Concrete Road Experiment Hole (with reinforcing rods installed)

Figure 85. Concrete Road Experiment Samples Being Backfilled (note the large rocks holding blocks from floating up out of position)

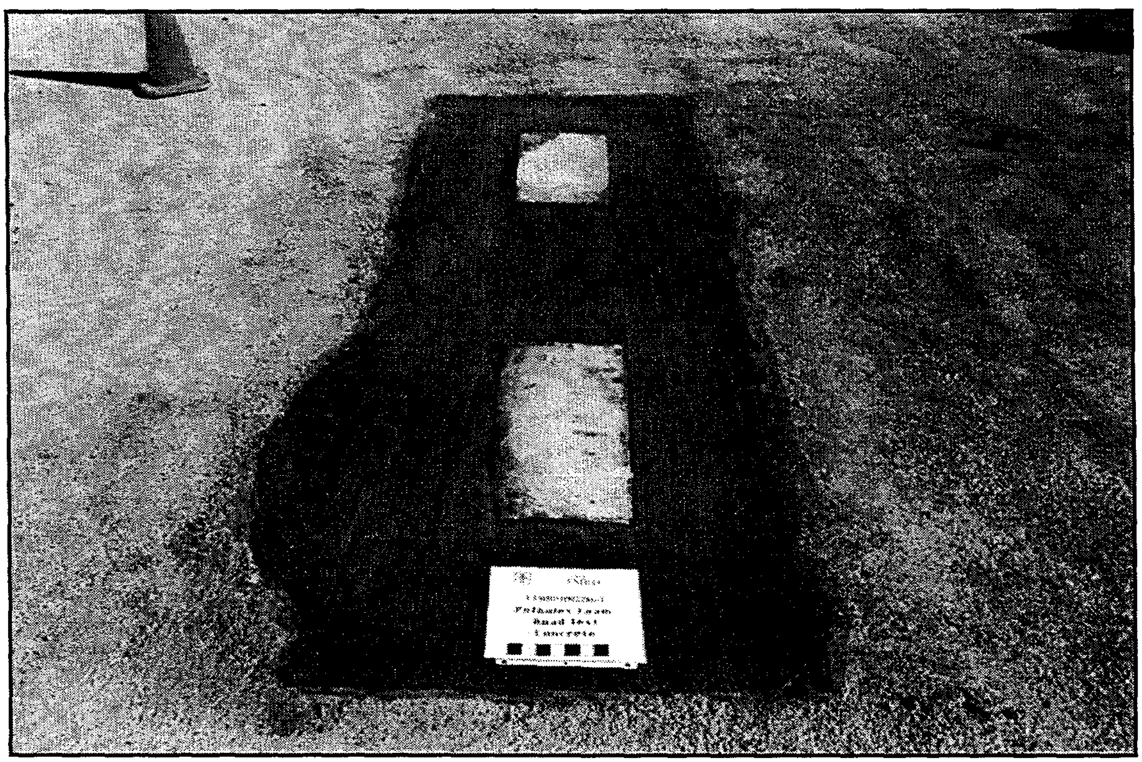


Figure 86. Concrete Road Experiment Pad on Completion

SECTION 4

Analyses

2.1.1 Preliminary Analyses

Several analyses were done to determine the feasibility of the basic concept. It was necessary to compare the existing data on strengths of generic foam as a function of density with the anticipated loadings. It was also necessary to scope the quantities and deployment rates that would be required in an operational application. The analyses were continually refined as more information became available from experiments and as the operational concept matured. These analyses used handbook formulas and values to begin the development process.

Figure 87 illustrates the strength of previously tested foams as a function of density. This is based on many experiments and was compiled by Peter Rand. Figure 88 indicates the ground pressure produced by representative military vehicles. Figure 89 compares these two data sets.

Figure 90 illustrates the quantities of foam required for representative operations, based on some simple assumptions of beach conditions and craft use. Figure 91 illustrates the quantities of foam deployed at different pumping rates. Figure 92 then indicates the relationship between deployment times and foam strength. Figure 93 illustrates foam volume produced by a fixed weight of material as a function of desired strength.

These analyses were used first as the basis for R. J. Kipp's scale model experiments, as reported previously.

As a result of these preliminary analyses, we decided with the concurrence of the TCG to proceed with experiments designed to refine our knowledge base.

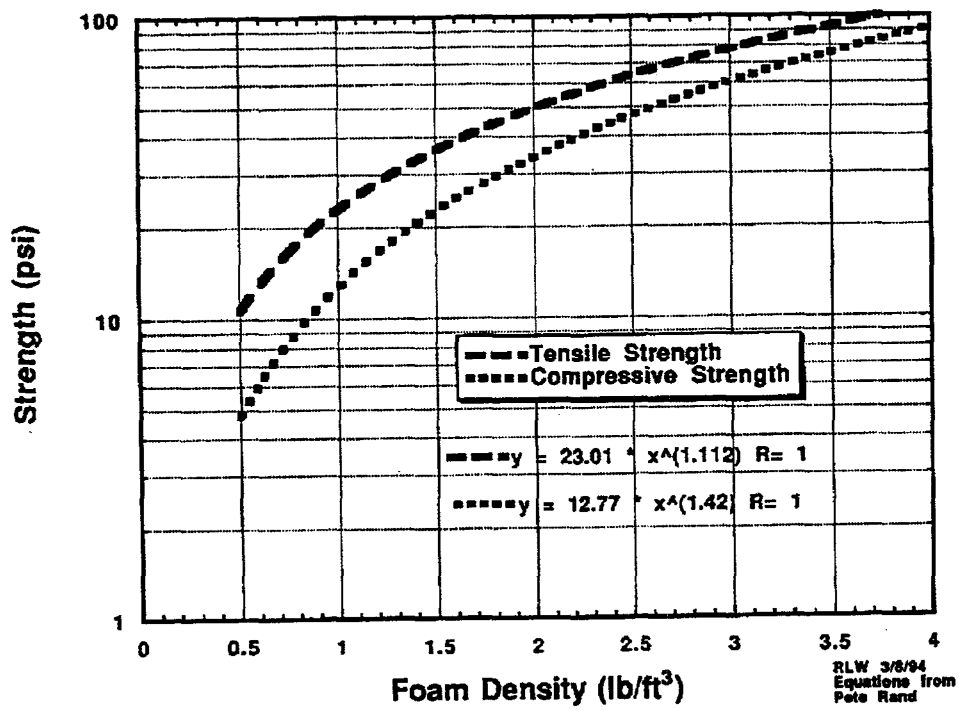


Figure 87. Tensile and Compressive Strengths of Rigid Polyurethane

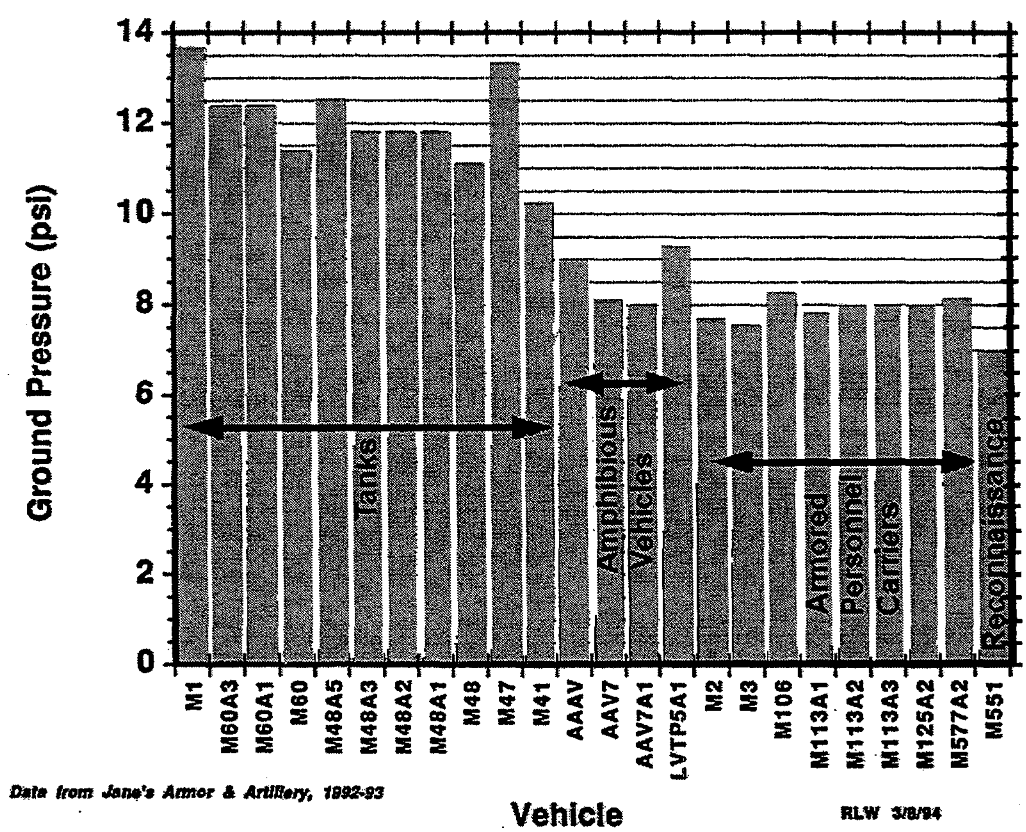


Figure 88. Bearing Pressure for U.S. Tracked Vehicles

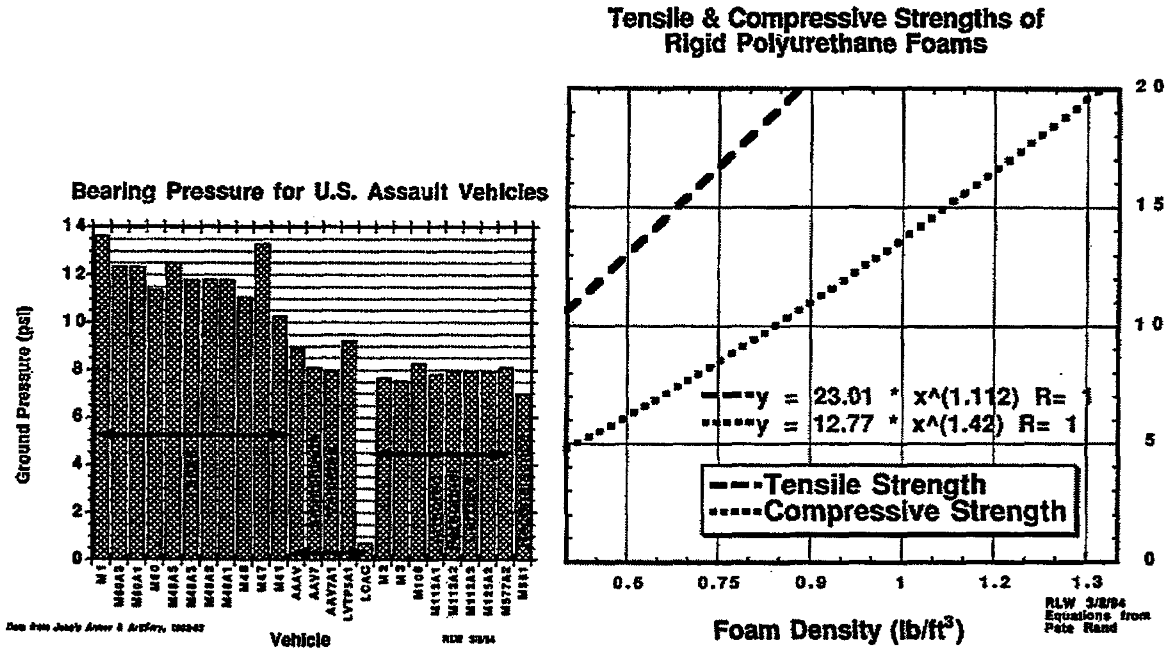


Figure 89. Comparison of Ground Pressure from Assault Vehicles with Foam Strengths

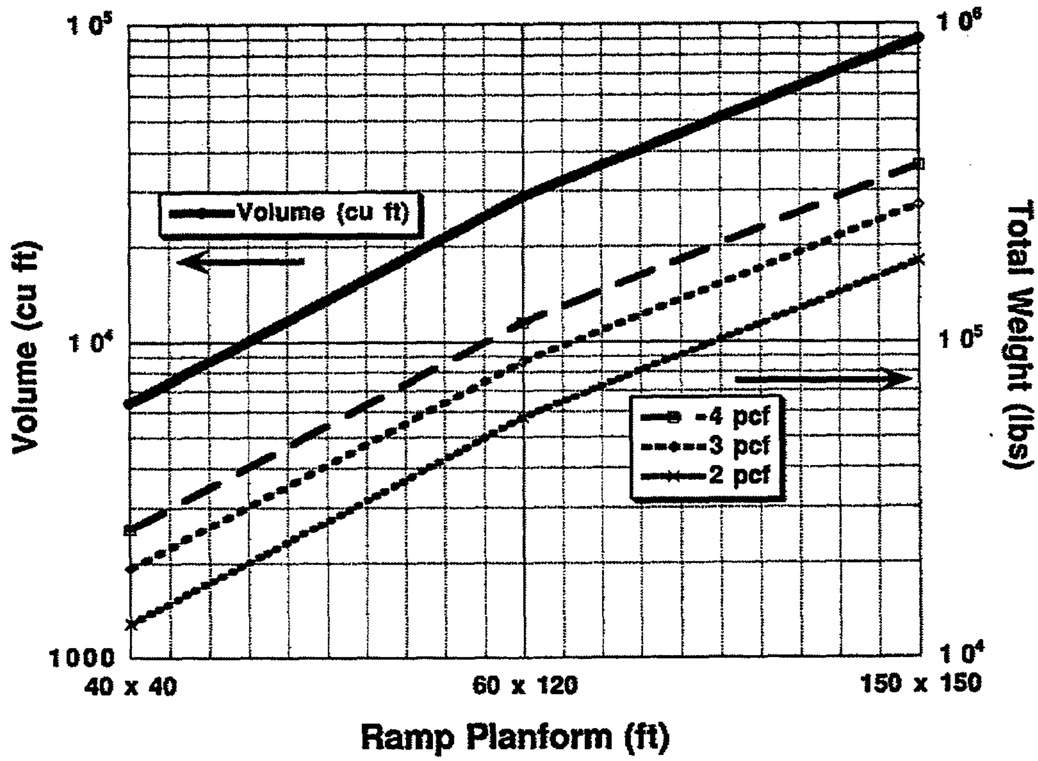


Figure 90. Foam Volume and Weights Required to Produce Ramps of Various Platforms

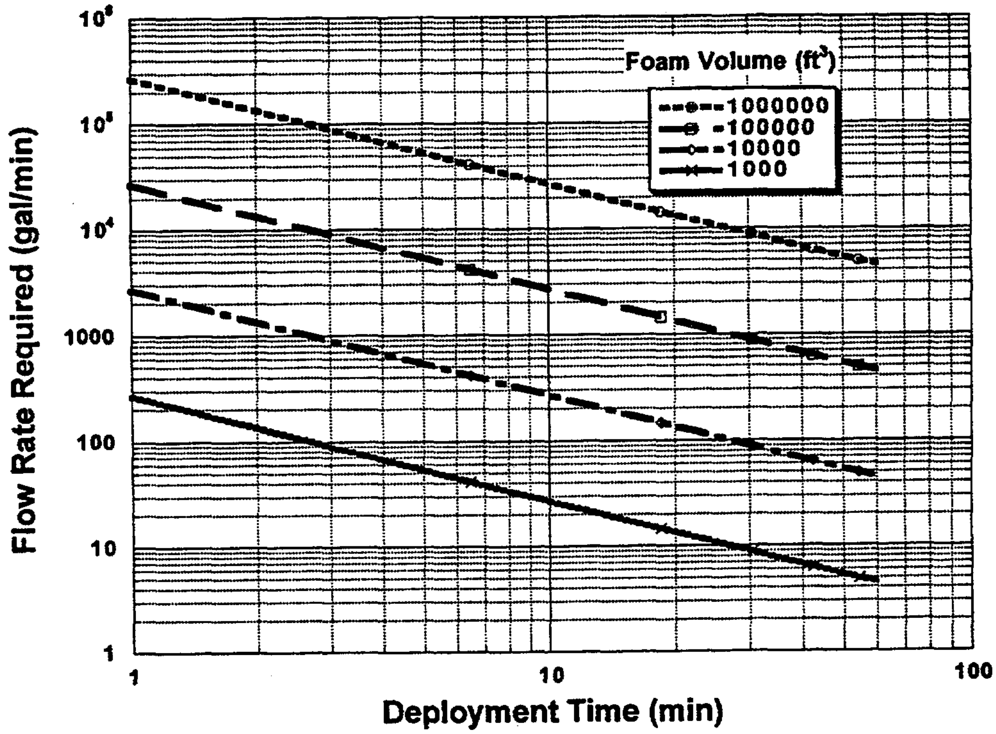


Figure 91. Flow Rate Required to Deliver 2 lb/ft³ Foam in Various Quantities within Specified Times

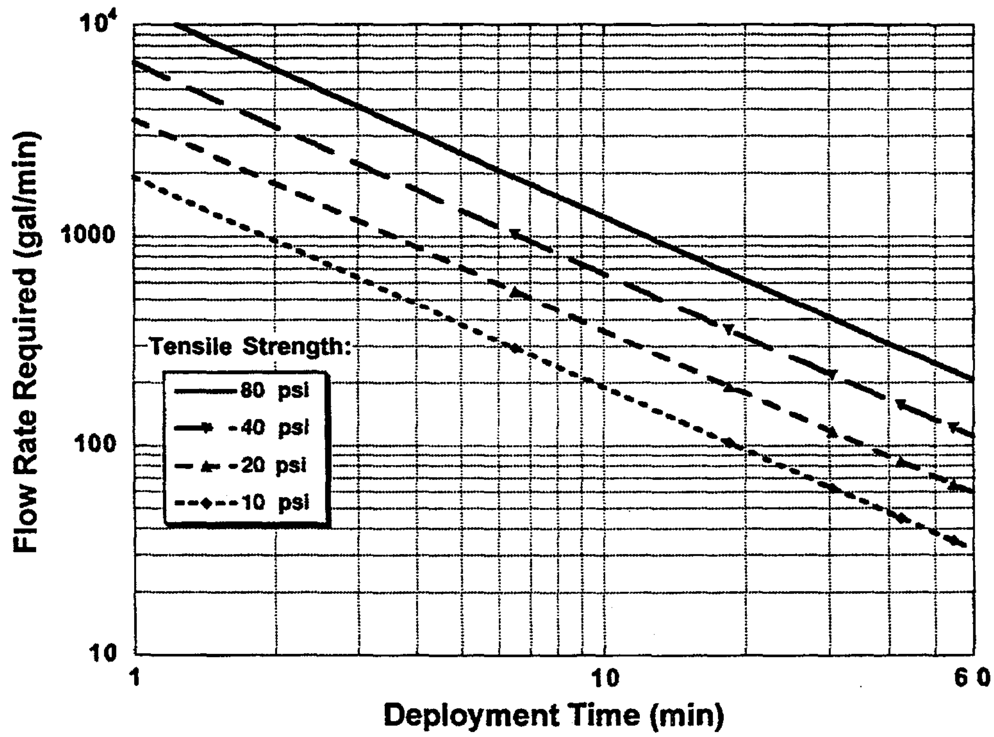


Figure 92. Flow Rate Required to Deliver 30,000 lb Foam in Various Strengths within Specified Times

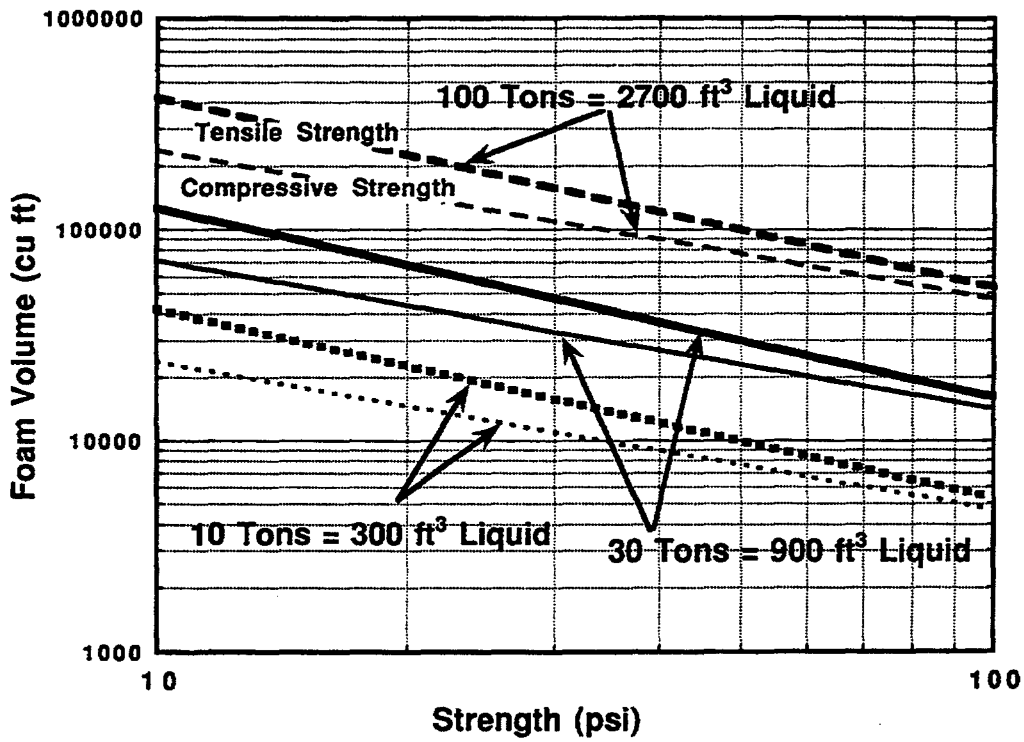


Figure 93. Foam Volume Produced by a Fixed Weight of Liquid to Achieve Desired Strengths

2.1.3 Explosive Effects

P. W. Cooper and S. R. Kurowski, Sandia National Laboratories, had investigated and modeled embedded detonations in foams in 1975 and reported their findings in a memorandum report dated October 6, 1975.

Their model was used to predict the approximate diameter of the cavities formed in 2 and 4 pcf RPF material. These predicted cavity diameters were then compared with actual measurements taken in the field at EMRTC. The empirical data for embedded charges were found to agree extremely well with the charts produced by Cooper/Kurowski.

Additionally, it was discovered that surface shots, where the explosive (C-4) charge is simply laid on the top surface of the block, formed cavities essentially identical in diameter to embedded charges in 2 and 4 pcf foams.

A series of predictive plots were extrapolated from Cooper and Kurowski's work to cover charges of 0.1 to 1,000 grams (C-4) and these were verified in the field experiments. When all the data are brought together, they plot as in Figure 94.

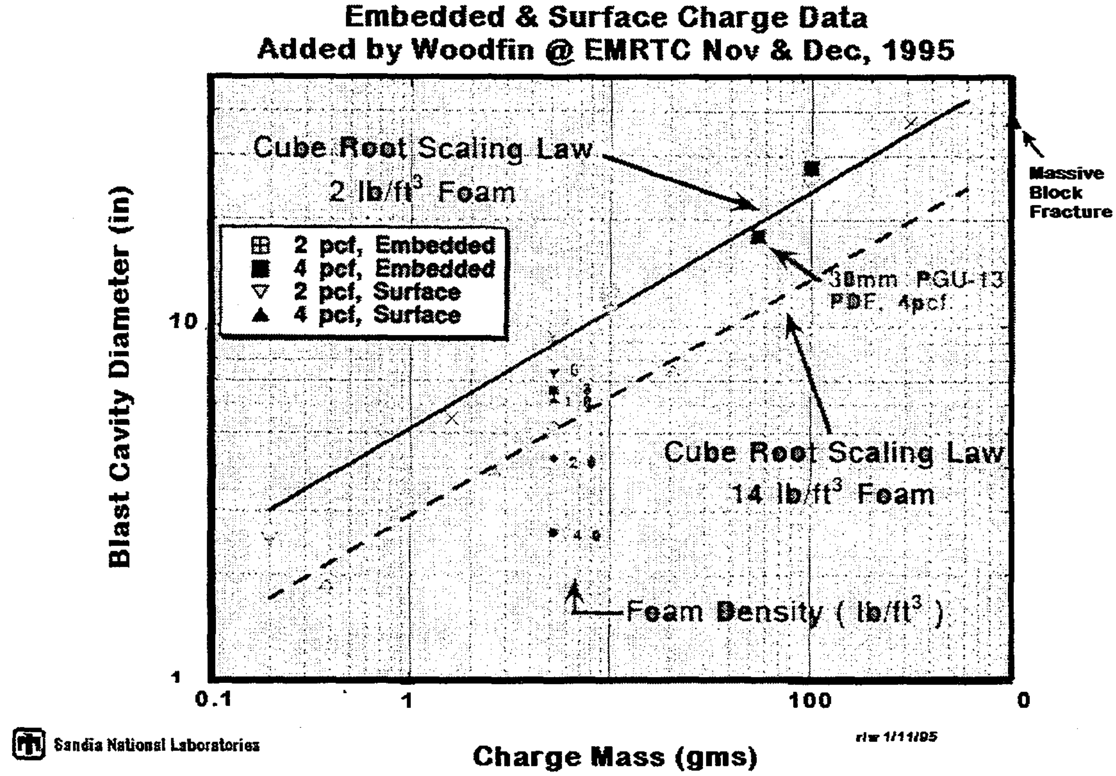


Figure 94. Data from Fully Embedded Explosive Tests on Foams

2.1.4 Magnetic Attenuation

We hypothesized that the foam material could be loaded with magnetic material of some sort to form a shield such that the magnetic signature of a vehicle passing over a roadway of foam would be so reduced or obscured that a magnetic mine below the foam would not be activated. We conducted an analysis to test that hypothesis. Details of the analysis are included as Appendix E.

The analysis showed that there was some attenuation from the magnetic particle suspension in the foam. However, it appears that nearly as much benefit may be had by the mere physical separation of the vehicle from the mine. In fact, when logistics are considered, it seems more effective to merely make the foam roadway thicker, if this kind of protection is sought. Therefore, this does not appear to be a fruitful approach at this time. This is principally due to the mass required to generate any effective magnetic shield.

2.1.5 Pressure Mitigation

The ANSYS modeling indicated that the pressure produced by a vehicle driving over a foam roadway drops off very quickly with depth. This is attributed to the sheer carrying capacity of the foam. No definitive experiments to measure this pressure have yet been conducted, but are anticipated for FY97. However, these preliminary results indicate that some reduction in pressure signature at the time is to be anticipated. This reduction will increase with foam thickness. The effect will be quantified in late FY96 and early FY97.

2.1.7 Trafficability

Introduction: Before the initial field experiments could be conducted, we had to choose the size of the blocks to be used and design a fixture for them. We wanted to ensure that the load would be applied in a realistic manner by the vehicles to be driven over it. This required the proper preparation of the approaches to the block, as discussed in Appendix C and the design of a fixture for proper support of the block itself.

The 54-inch cube blocks were chosen principally because available fabrication methods could be readily adapted and because they fit well on standard pallets, allowing easy handling by fork truck. After the size was chosen, it became necessary to estimate the stresses and deflections expected in the field experiments.

Model: These calculations were done with the ANSYS finite-element code. For these estimates, only linear elastic material models were employed. The overall condition of the blocks was considered to be adequately represented by a state of plane stress, which is a better model of the tracked vehicle loading than of the tired vehicle loadings. Local details of the loading interface were not attempted. Loads were modeled as simple pressure loads, representing both the M60 tank and the M110. Symmetry was exploited; no off-center loadings were considered. The blocks were constrained by a simply supported condition at each node along their base. Both 2 pcf and 4 pcf blocks were analyzed. The following material properties were used:

Density (pcf)	Young's Modules (psi) (compressive)	Poisson Radio	Yield Stress (psi)
2	799	0.3	49.7
4	2180	0.3	107

Results: No stresses approaching yield were found. Deflections were modest, even under the load. Both pressures and displacements became small very rapidly with distance from the load. Figures 95 through 97 illustrate the results of this analysis, as explained in their captions.

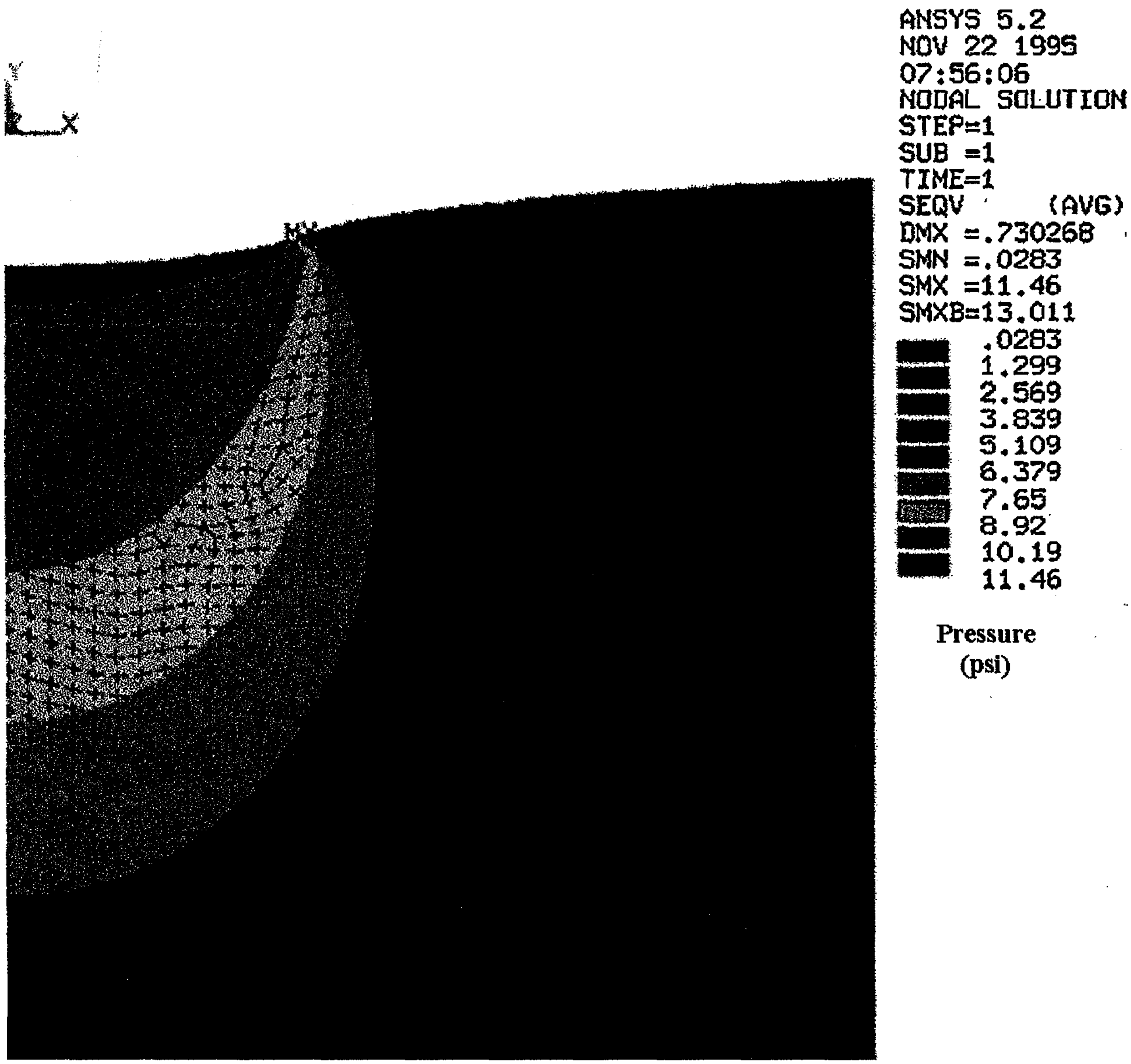


Figure 95. Plane Stress Pressure Load in Top 1/3 of 54-in Block (M60 on 2 pcf foam)

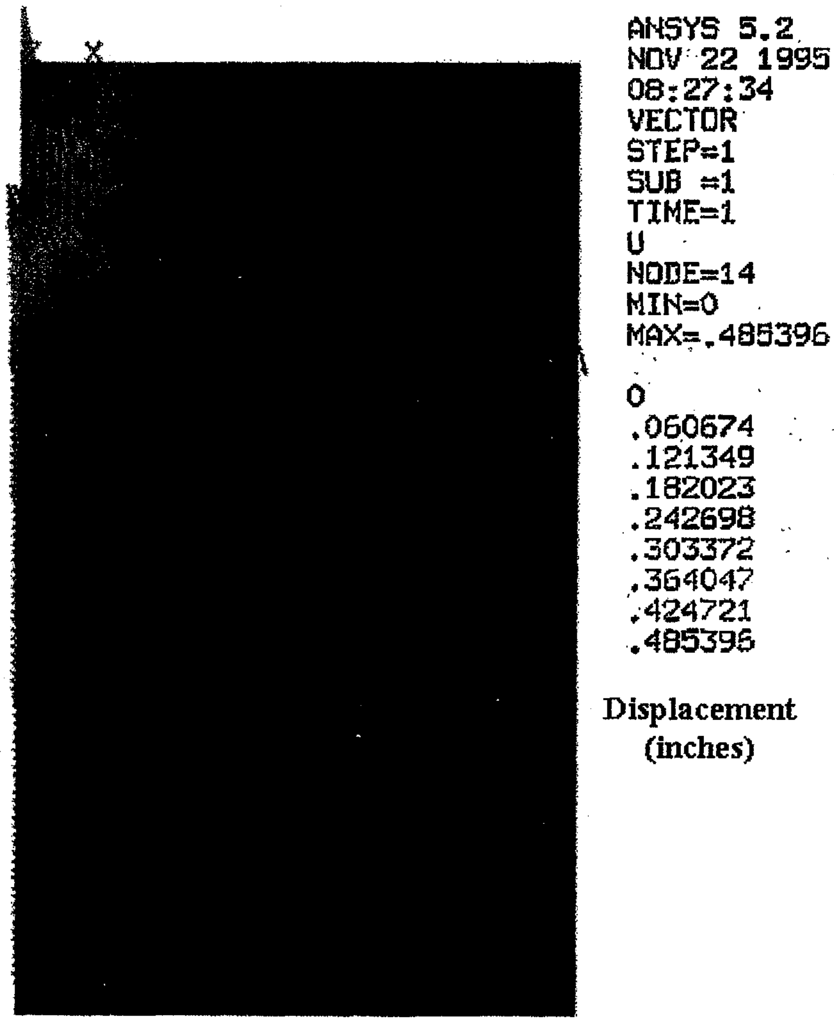


Figure 96. Displacements Resulting from Plane Stress Solution, Pressure Load (M110 on 2 pcf Foam)

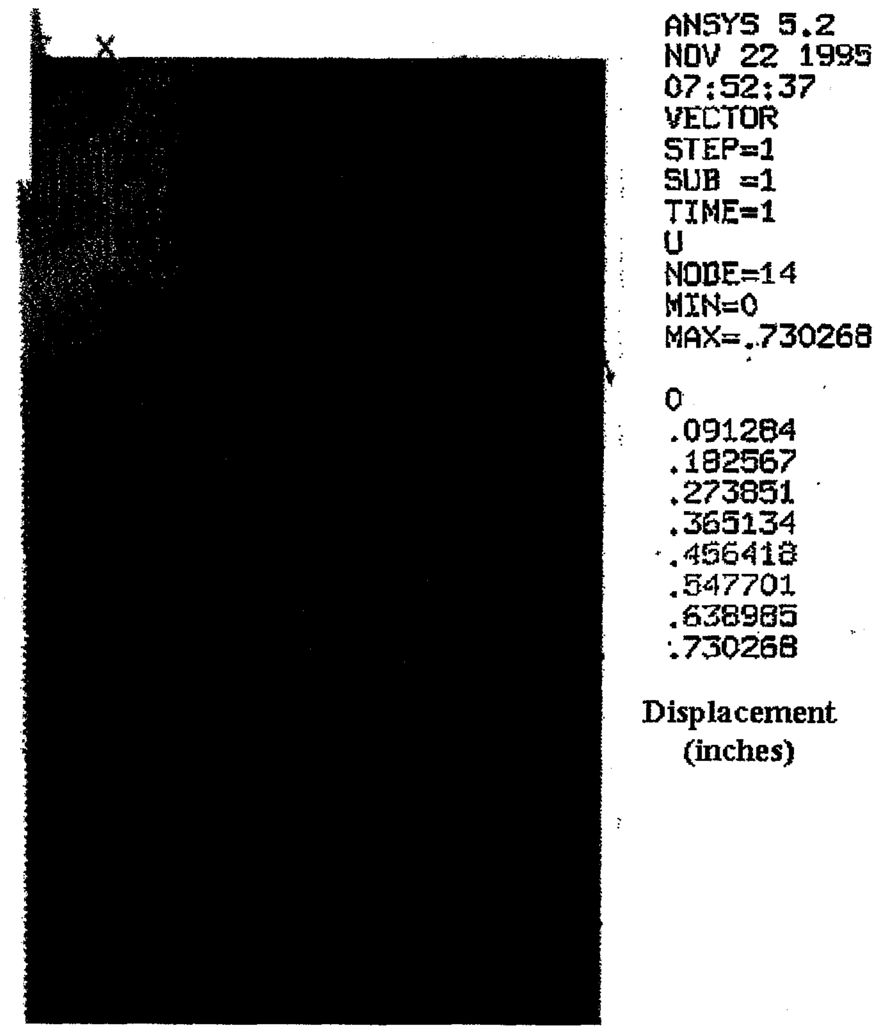


Figure 97. Displacements Resulting from Plane Stress Solution, Pressure Load (M60 on 2pcf Foam)

2.1.8 Block Tilt Analysis

There will be substantial work devoted to "Barge Seaworthiness." A first question can be answered readily, namely "How big must a block of foam be to support a tank?"

For this analysis, we considered the two-dimensional case of a floating block of foam in the form of a rectangular parallelpiped with dimensions shown in Figure 98. C.G. represents the center of gravity and C. B. the center of buoyancy. An off-center load, T, is applied at a distance, e, from the centerline. The block is considered rigid, the worst case for buoyancy, and homogeneous. The subscript, s, refers to that portion of the block below the waterline. The "original waterline" is for e = o.

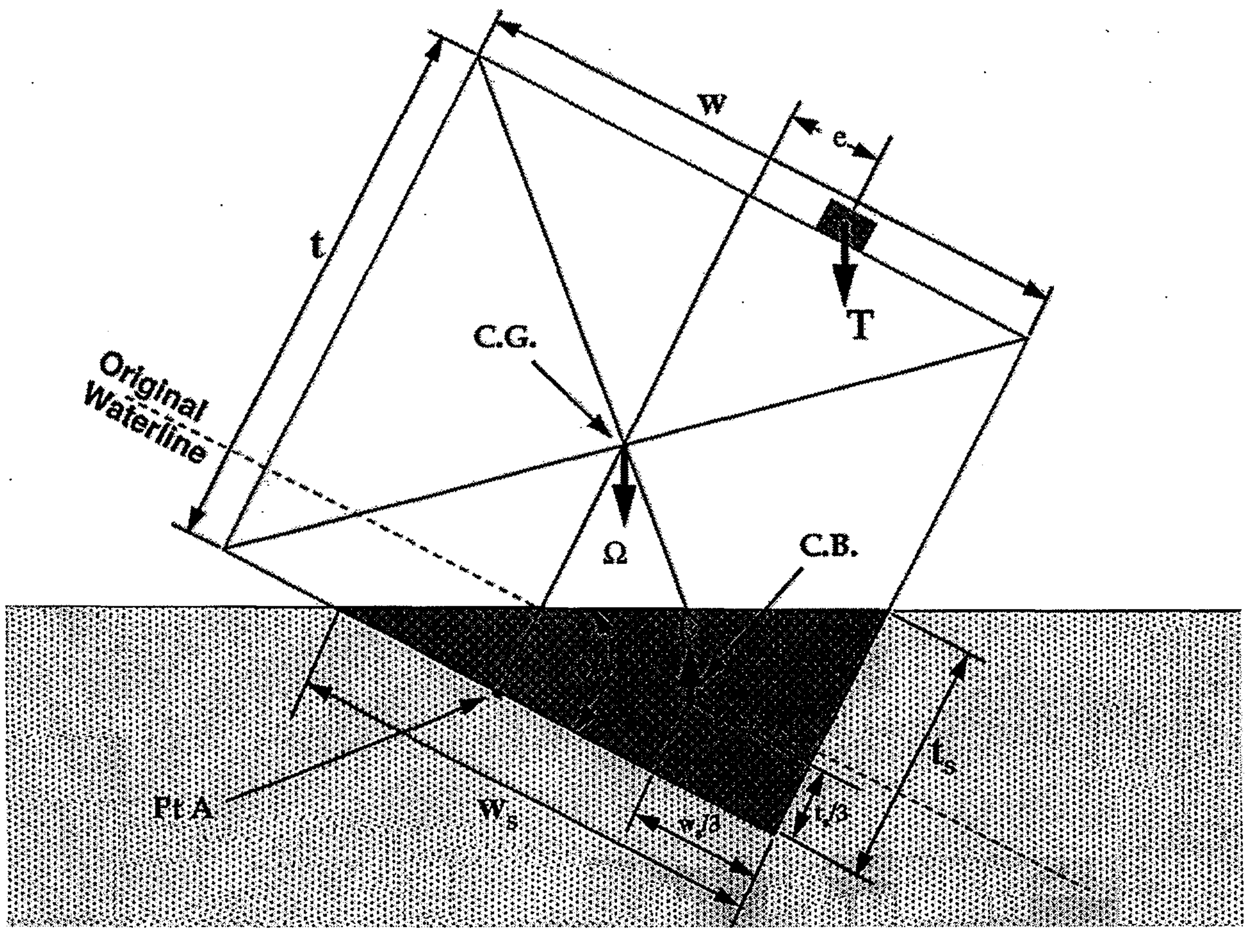


Figure 98. Diagram for Block Tilt Analysis

By summing moments about Point A, the following equation is derived:

$$\frac{\Omega t}{2}\sin\alpha + T(t\sin\alpha + e\cos\alpha) = B\cos\alpha\left(\frac{W}{2} - \left[\frac{W_s - t_s\tan\alpha}{2}\right]\right)$$

While it would be most desirable to express α in terms of e, that proved most difficult. Therefore, the inverse expression was derived:

$$e = \frac{B}{T}\left\{\frac{W}{2} - \frac{\sqrt{wd}\ \sqrt{actn\,\alpha}}{3}\left[1 - \tan^2\alpha\right] - \frac{\Omega t}{2B} - \frac{T}{B}t + \tan\alpha\right\}$$

This equation is valid for $W_s \leq W$ or $\alpha \geq \tan^{-1}\left(\frac{2d}{w}\right)$.

A parametric solution of this equation, using an EXCEL spreadsheet, was performed. The foam density used was 3 pcf and a thickness of 4 ft. Sea water density was taken as 64 pcf. The load, T, was taken as 53 tons to represent the M60 tank. The maximum tilt obviously occurs when $e = \frac{W}{2}$, that is, as the tank just reaches the edge of the block.

Figure 99 illustrates the tilt angle produced by the eccentric load for one size foam block. Figure 100 illustrates the maximum tilt produced, i.e., with the load at the block edge for blocks of different sizes. Figure 101 is similar, but illustrates the tilt in % grade rather than degrees. Figures 102 and 103 show tilt angle as a function of block volume.

Examination of the figures reveals that any block large enough to be operationally useful is not subject to excessive tipping due to eccentric loading. Scaled down, these data will be used in planning experiments for Phase 2.

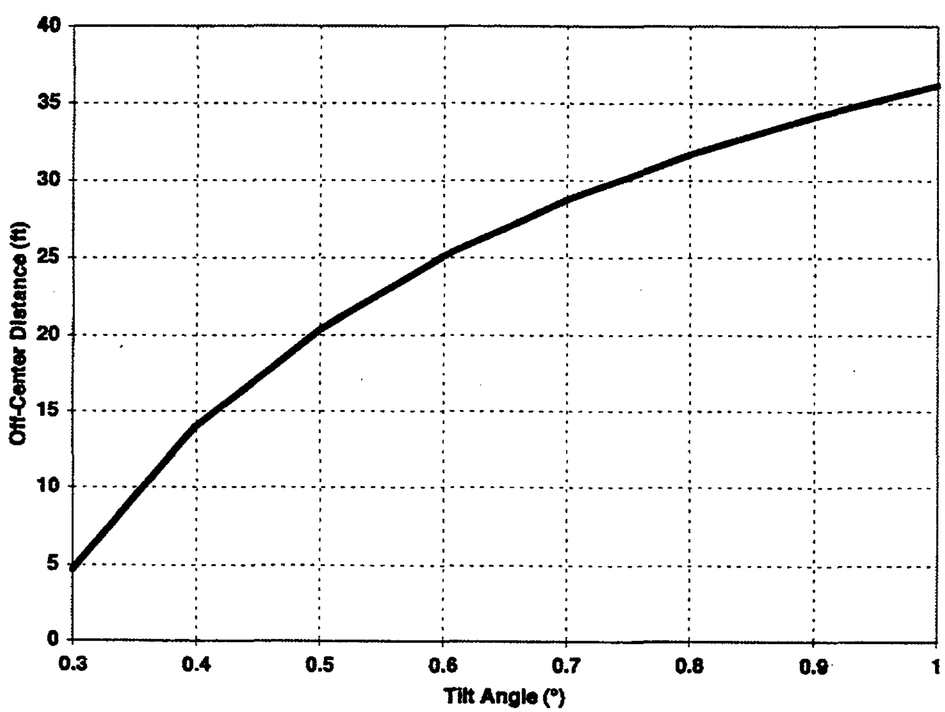


Figure 99. Effect of Eccentric Load (on 4 ft thick, 3 pcf, floating block, 100 ft long x 80 ft wide)

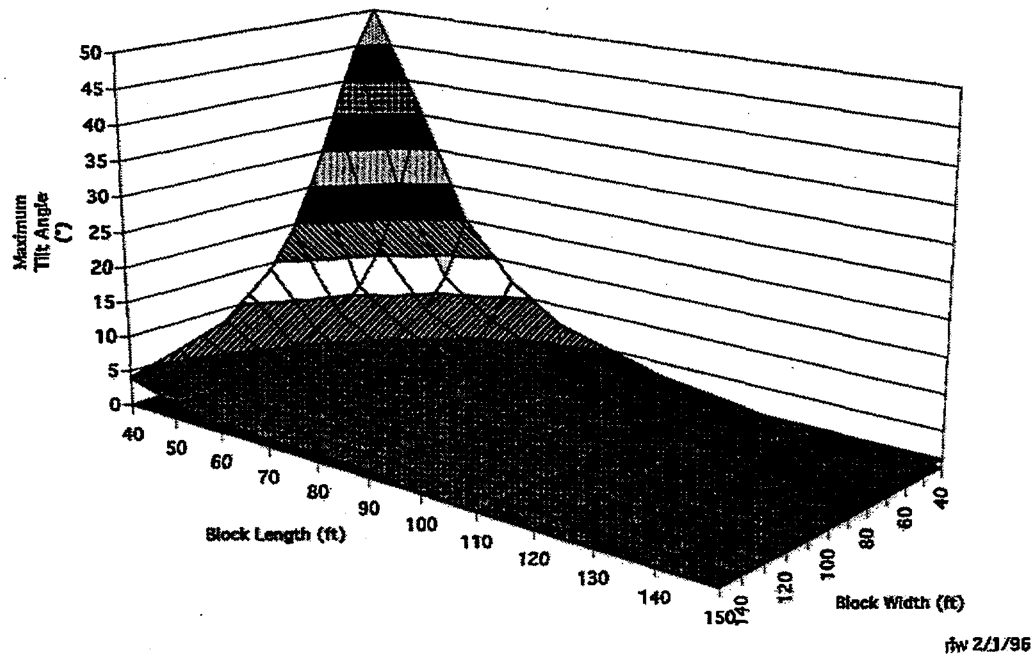


Figure 100. Maximum Tilt (produced in floating 3 pcf foam block, 4 ft thick, by edge load of 53 tons)

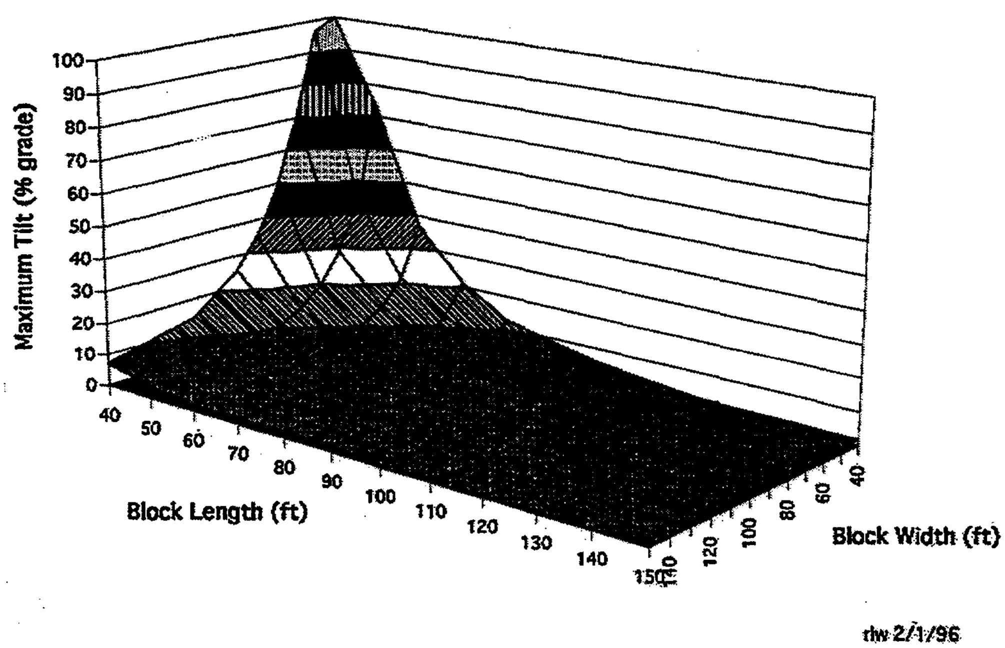


Figure 101. Maximum Tilt (produced on floating 3 pcf foam block, 4 ft thick, by edge load of 53 tons)

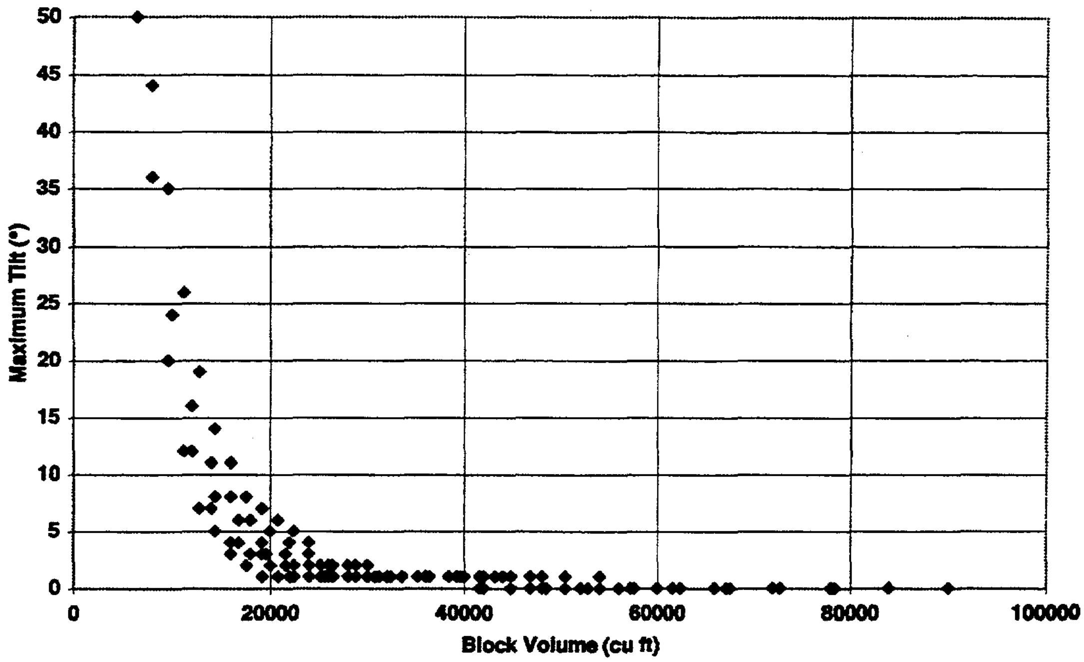


Figure 102. Maximum Tilt (produced on floating 3 pcf foam block, 4 ft thick, by 53 ton edge load)

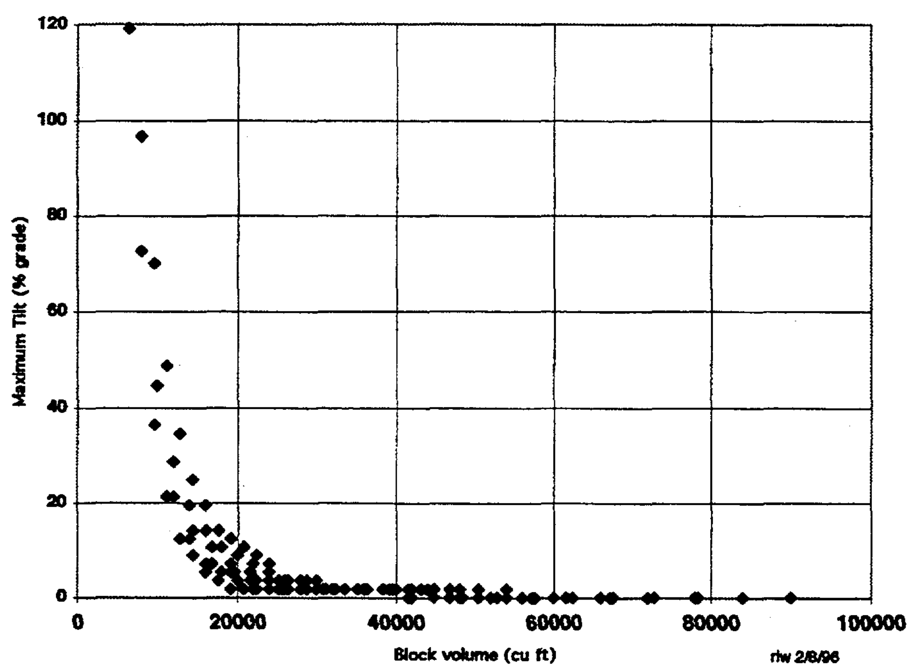
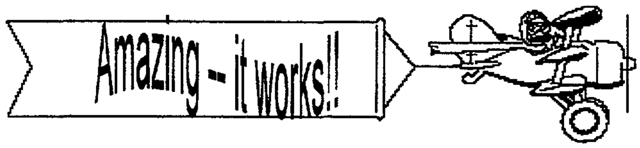


Figure 103. Maximum Tilt (produced on 3 pcf foam block, 4 ft thick, by 53 ton edge load)

SECTION 5

Phase 1 Conclusions



The objective of Phase 1 was to examine those areas of concern in this application of RPF material, expressed by the TCG and other Navy and Marine Corps advisors. We wanted to rapidly determine whether RPF material was suitable for military use in an assault roadway.

The results of this phase of the work clearly indicate the following:

- RPF can be formed with the required structural properties,
- RPF poses no extraordinary fire danger,
- RPF absorbs substantial blast energy with controllable and repairable results,
- RPF can be formed in/under water with acceptable properties,
- RPF is not destroyed by bullet impacts but neither does it offer substantial protection to troops,
- RPF material is environmentally benign when cured; however, one of the constituents is a respiratory irritant and must be handled with care,
- RPF may be formed with acceptable properties over a useful range of water and air temperatures, and
- RPF may be formed with acceptable properties without requiring precise mix ratios.

SECTION 6

Other Possible Applications

During these Phase 1 experiments, it has been demonstrated that RPFs can carry a substantial traffic load. They also can be placed rather quickly under physically difficult conditions and have the inherent advantage of expanding for use so that much less volume must be carried than that needed in the application. These RPFs may prove useful in a variety of other situations, such as:

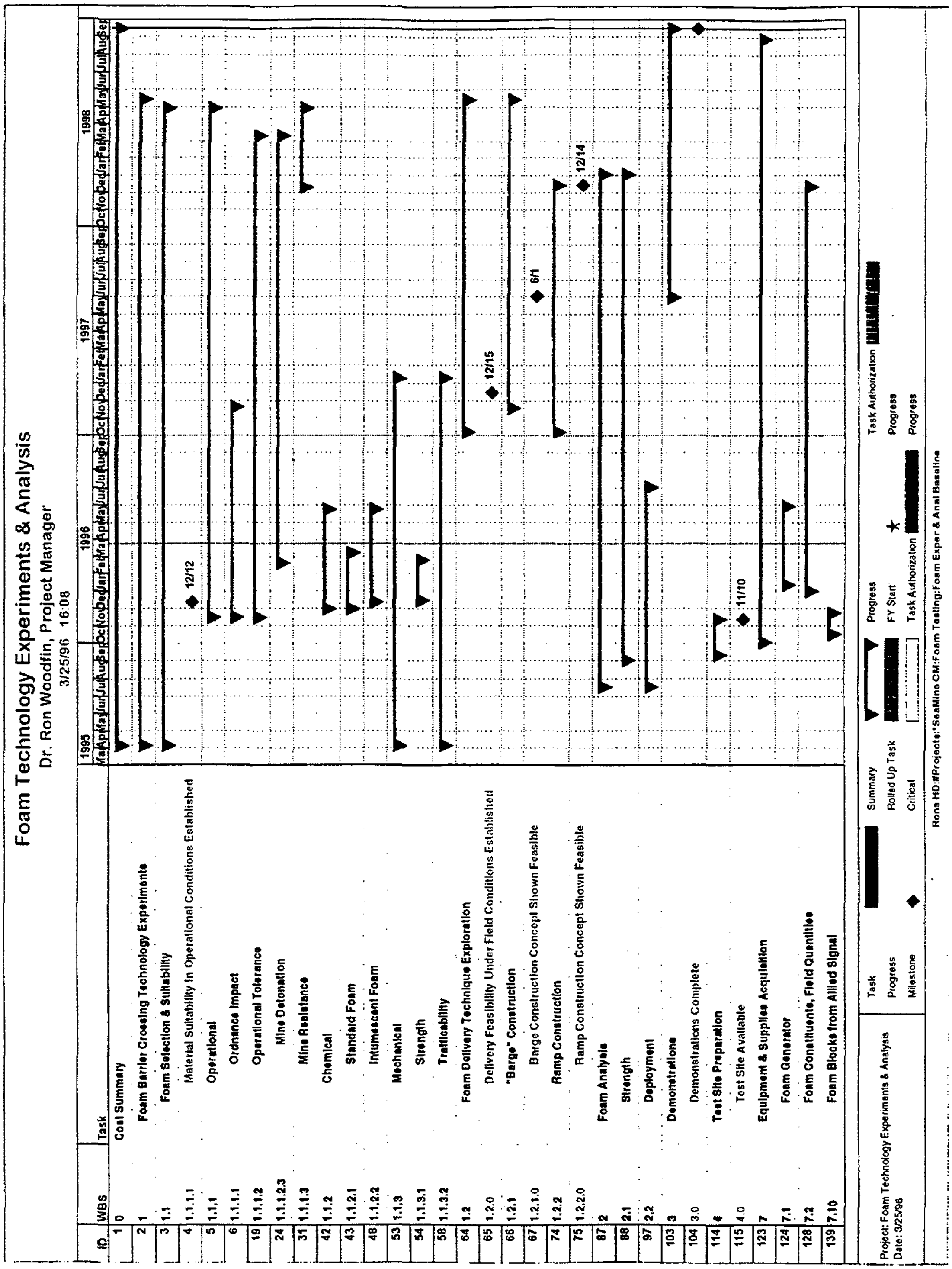
- construction of a floating base course and roadway over water,
- construction of roadways over very difficult terrain (swamps, tundra, etc.),
- construction of temporary vehicle crossings over ditches or tank traps,
- construction of coverings over anti-personnel minefields to suppress or inhibit detonation,
- rapid repair of shell, bomb, or pothole damaged roadways,
- immobilization of certain mine firing mechanisms,
- absorption of part, or all, blast energy from mines or other ordnance,
- rapid repair of damaged or cratered runways,
- post disaster stiffening of damaged buildings and bridges,
- construction of emergency floating bridges, and
- emergency repairs of floating equipment.

Sandia National Laboratories Disclosure of Technical Advance number SD 5795 was filed on January 22, 1996, detailing some of the patentable aspects of this kind of foam applications.

In order to prove any of the conceptual uses above, a significant investment of time, monies, and materials will be needed. Some of the simpler proposed applications could be tested and developed in a year or two at a cost of several hundred thousand dollars. Other applications, particularly those that would require engineering of large, mobile, foam dispensing equipments, are multimillion dollar programs requiring several years work.

SECTION 7

Anticipated Project Schedule



APPENDIX A

SPECIFICATIONS FOR FOAM DISPENSER

Supply two-component rigid polyurethane foam dispenser. Dispenser shall include all hoses, regulators, or other equipment necessary to connect to electrical and gas inputs to dispenser. All equipment must meet industry standards for pressure and electrical safety.

1. Dispenser must be packaged for field use.

2. Dispenser feed must be from either/or 55 gallon drums or 250 gallon totes.

3. Dispenser throughput: approximately 100 pounds/minute.

4. Mixing: static mixer. Other types will be considered if deemed necessary.

5. Dispense type: pour.

6. Dispenser must be equipped with a pressurized solvent flush system to clean static mixer.

7. Lines: approximately 50 feet long.

8. Dispenser shall be equipped with nucleating gas injection system.

9. Heating: heated pots, heat exchangers, or heated lines with a temperature control system shall be included.

10. Component supply:

    a) if pressure pots are used, minimum size is 50 gallons and equipment must be supplied to feed pressure pots from 55 gallon drums or 250 gallon totes.

    b) If intended supply is from 55 gallon drums and totes, all equipment necessary to supply component A and B to metering pumps must be supplied.

11. Component Ratio:

    Either

    a) 1:1 by volume only, or

    b) Easily adjustable multiple ratio system with all equipment and readouts to assure mix accuracy.

12. Dispenser must be capable of satisfactorily mixing and pouring NCFI 811-91 rigid polyurethane foam system.

Cream Time: 50 - 60 seconds at 72°F
Rise Time: 3 - 4 minutes

Viscosities: "A" component - 320 cps (Sandia data)
"B" component - 580 cps (Sandia data)
Brookfield #3 spindle at 60 rpm. Measurement taken at 15 seconds after shear applied.

For further information on foam system, contact North Carolina Foam Industries at: (910) 789-9161

13. Price should include personnel for one day to set up foam dispenser, train an operator, and demonstrate the dispenser in Socorro, NM.

14. Quote should include:

- A list of recommended spare parts for dispenser maintenance
- A recommended solvent for the solvent flush system
- Electrical requirements for dispenser operation
- Compressed air requirements for dispenser operation
- Other gas required for dispenser operation

Possible Suppliers

1. Edge-Sweets Company
2887 Three Mile Road NW
Grand Rapids, MI 49504-1386
Attn: Stephen Hoffman
(616) 453-5458

2. North Carolina Foam Industries
P.O. Box 1528
Mount Airy, NC 27030
Attn: Ray M. Mackey
(910) 789-9161

3. Premium Polymers (5/91)
9721-T Hwy. 290 East
Austin, TX 78760
Attn: Armand Gonsoulin
(800) 756-3626

4. Decker Industries
P.O. Drawer "R"
5051 S. E. Federal Hwy.
Port Salerno, FL 34992
Attn: A. William Shaw
(407) 283-4004

APPENDIX B

CHEMICAL LABORATORY EXPERIMENTAL RESULTS

July 27, 1995	Foams for Barrier Crossing - Initial Properties
January 11, 1996	Foams for Barrier Crossing -Effect of Water Temperature, Component Temperature, and Component Ratio on Foam Reactivity and Density
February 29, 1996	Foams for Barrier Crossing - Evaluation of Intumescent Foam, Exotherm Temperatures, and Foam-to-Foam Bonding
March 15, 1996	Foams for Barrier Crossing - Mechanical Properties as a Function of Density, Temperature, and Time After Pour

Sandia National Laboratories

Albuquerque, New Mexico 87185-0368

date: July 27, 1995

to: R. Woodfin, MS, 9122

from: P. B. Rand, Brad Hance, 1811, MS 0367 & M. Stavig, MS, 2472

subject: Foams For Barrier Crossing - Initial Properties

Rigid polyurethane foams are proposed to form a passageway over the obstacles on a barricaded beach. The foam would cover both the shallow surf zone and the beach. As a first step for this project we have evaluated several candidate foams. Laboratory evaluations included processability tests and a look at their foamability when poured into water. Compression properties, parallel and perpendicular to the foam rise direction, were also determined.

From an initial list of eight foam suppliers we obtained five commercially available foams from three suppliers. Our request for foams to suppliers listed a number of requirements which included the following:

a) Polymeric isocyanate based
b) Ambient temperature cure
c) Some level of fire retardancy
d) Large pour capability without splits or tears
e) Large pour capability without scorching
f) Processable over maximum temperature range possible (50°F to 90°F?)

The processability of the foam was evaluated using tests to measure rise time and tack free time. All foams were mixed using a Conn Blade Mixer at approximately 1500 rpm. The rise time is the time from the initial mixing until the foam stops rising. As the name implies, the tack free time is the time until the top of the foam is no longer sticky. Cup density is determined by pouring 200 grams of mixed components into a tared three quart cardboard tub. After the foam sets (30 minutes) the top of the foam is cut off level with the top of the container. Density is calculated using the foam weight and the container volume. The data from these tests are given in Table B-1. One of the foam systems, Stathane 6502 MSH, reacted very quickly and made foams with splits. This foam was dropped from further testing.

Also included in Table B-1 are the results of our foaming tests in water. For this test 200 grams of mixed foam ingredients were poured into a container with three quarts of water approximately two inches deep. As the density of the mixed ingredients is higher than water, the liquid would sink to the bottom of the polyethylene container and rise only when it started to foam. In all cases this had an adverse, but not fatal, effect on the foaming and the foam. Only one foam system gave good quality foams after water immersion. That was the NCFI 811-91. The other three gave foams that either had poor quality cell structure, shrank, or were brittle.

The compression properties were determined on two inch cubes per ASTM D-1621. Typical stress strain curves from these tests are presented in Figures B-1 and B-2. The compressive strength and moduli data are given in Table B-2. To allow a better foam to foam comparison compressive strength and moduli data were normalized to two pounds per cubic foot density using long established stress density relationships.

The only laboratory testing pending is the determination of the effect of component temperature on the processability of the foam. This will be our first task next fiscal year if this project is funded. The next step will be to purchase a foam machine to allow intermediate scale field testing of a couple of candidate foams. The North Carolina Foam Industries NCFI 811-91 and the Premium Polymers PP 475-20 look like excellent candidates for further testing. A higher density version of the PP 475-20 would be necessary to meet the minimum density requirement of 2.0 lbs/ft^3.

Table B-1
Reactivity, Density, and Water Immersion of Rigid Polyurethane Foams

Material	Manufacturer	Rise Time (Min)	Tack Free Time (Min)	Cup Density (lbs/ft^3)	Cube Density (lbs/ft^3)	Water Immersion Comments
NCFI 811-91	NC Foam Industries	3:21	4:38	2.60	2.11	Sinks, Foaming Slow, Good Quality
PP 475-20	Premium Polymers	2:11	3:07	1.46	1.26	Sinks, Rose Quickly, Fair Quality
Stathane 4802 W	Expanded Rubber and Plastics	3:09	6:03	2.54	2.29	Sinks, Rose Quickly, Foam Shrank
Stathane 6603 MSH	Expanded Rubber and Plastics	4:47	5:23	2.70	2.26	Sinks, Very Slow, Foam Brittle
Stathane 6502 MSH	Expanded Rubber and Plastics	2:18	2:37	2.62	No Data	Too Fast, Splits - No Further Evaluation

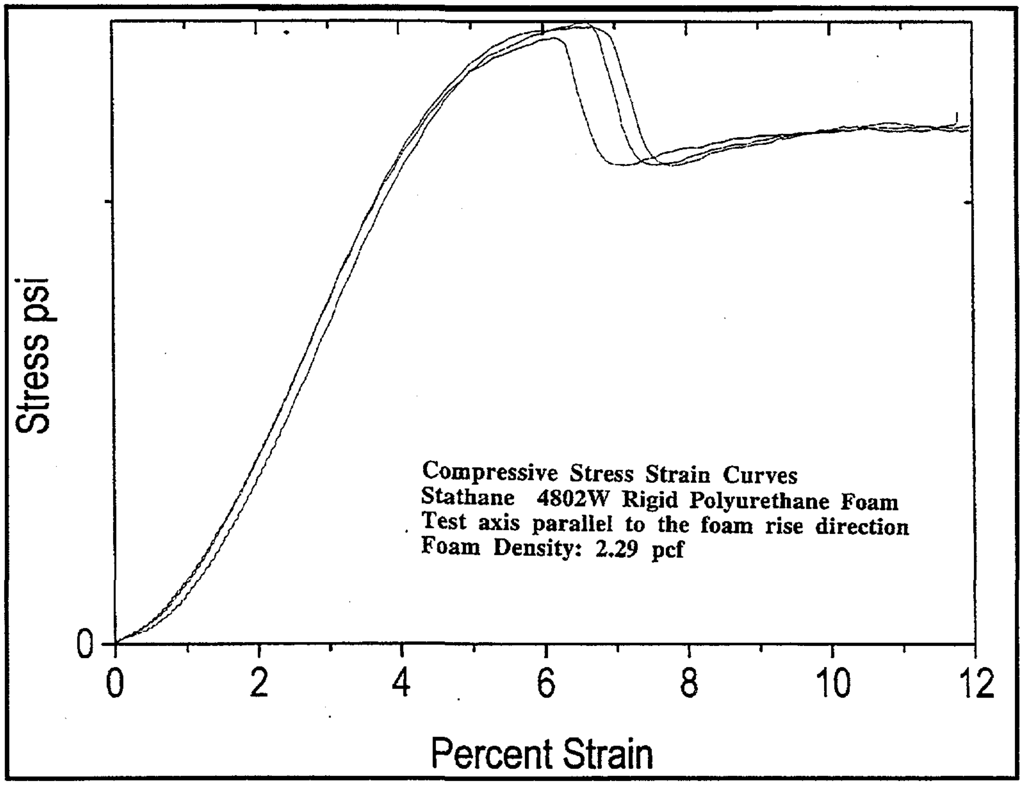


Figure B-1

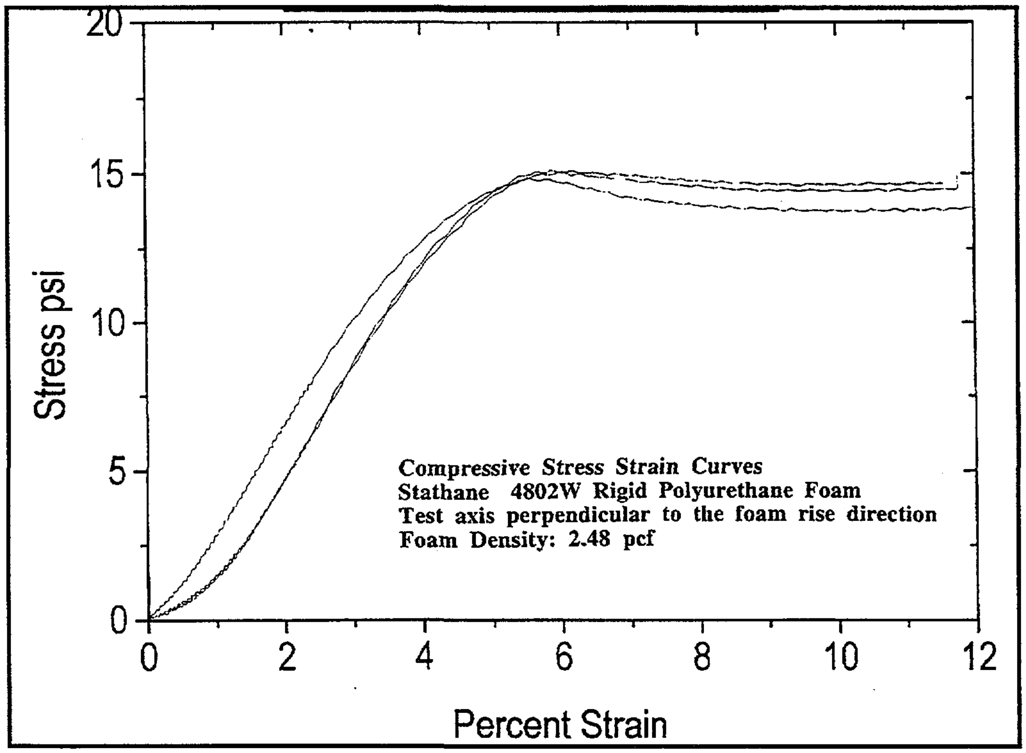


Figure B-2

Table B-2
Rigid Foam Compressive Properties

Material	Manufacturer	Test Direction	Density (lbs/ft^3)	Compressive Modulus (psi)	Compressive Strength	Normalized Strength (psi) (3)	Normalized Modulus (psi) (3)
Test Axis Parallel to Rise Direction							
NCFI 8110-91 Standard Deviation	North Carolina Foam Industries	Parallel	2.11	923 62.6	43.5 1.8	40.3	854
PP 475-20 Standard Deviation	Premium Polymers	Parallel	1.26	268 21.4	15.9 0.3	30.9	521
Stathane 4802 W Standard Deviation	Expanded Rubber & Plastics	Parallel	2.29	905 6.6	34.6 0.44	28.5	745
Stathane 6603 MSH Standard Deviation	Expanded Rubber & Plastics	Parallel	2.26	1134 47.6	44.8 1.4	37.6	951
Test Axis Perpendicular to Rise Direction							
NCFI 811-91 Standard Deviation	North Carolina Foam Industries	Perpendicular		360 15.7	18.5 0.4	17.0	331
PP-475-20 Standard Deviation	Premium Polymers	Perpendicular		139 0.4	8.42 0.15	16.2	267
Stathane 4802 W Standard Deviation	Expanded Rubber & Plastics	Perpendicular		382 6.6	15.0 0.13	11.0	280
Stathane 6603 MSH Standard Deviation	Expanded Rubber & Plastics	Perpendicular		414 33.1	23.1 1.0	18.2	326

Notes: 1. All Data are the average from three specimen.
2. All tests were run per ASTM D-1621.
3. Data normalized to 2.0 pcf using stress density equation.

Sandia National Laboratories

Albuquerque, New Mexico 87185-0368

date: January 11, 1996

to: R. Woodfin, MS, 9122

from: P. B. Rand, Brad Hance, 1811, MS 0367

subject: Foams For Barrier Crossing - Effect of Water Temperature, Component Temperature, and Component Ratio on Foam Reactivity and Density

Reference: Memo "Foams For Barrier Crossing - Initial Properties", from: P. B. Rand, B. G. Hance, 1811& M. Stavig, MS, 2472 to R. Woodfin, 9122, 7/27/95.

Summary: Foam reactivity and density were determined for foams immersed in water at 40, 60, and 80°F, for foams made with the components temperature conditioned at 40, 60, and 80°F, and for foams mixed off-ratio. Although effected by these environments and mix ratios, foams were made at all test conditions.

Rigid polyurethane foams are proposed to form a passageway over the obstacles on a barricaded beach. The foam would cover both the shallow surf zone and the beach. In this second series of tests we have evaluated the effects of water and component temperature on foam reactivity and density. We also evaluated foam that was mixed "off-ratio" to evaluate the effect of poor mix ratio control. The foam system used for all evaluations was North Carolina Foam Industries NCFI-811-91. This foam was selected from a field of five foams from three suppliers as reported earlier.

In all tests 207g of foam components were mixed for 25 seconds using a "Conn" blade mixer. The foam was poured immediately after mixing. The mixed components were poured into a 1/2 gallon paper tub and allowed to foam. Foam reactivity was determined by measuring the rise and tack free times of the foam. "Cup" densities were obtained in these tests by determining the density of the foam in the 1/2 gallon tub. In the water immersion tests the mixed foam components were poured in the temperature conditioned water and allowed to foam. The density of the water immersion samples was determined from core samples taken from the cured foam.

Tests

One concern in the proposed use is the effect of water and water temperature on the foam formation. In these tests we evaluated the effects of water temperature on foaming performance. The water temperature was controlled using a coiled copper tube heat exchanger in the water bath. A mixer was used to assure constant temperature in the water. Tests were run at water temperatures of 40, 60, and 80°F. The mixed foam components are denser than water and therefore sink when poured into the water. When foaming begins the foam rises to the surface and cures. The results of these tests are reported in Table B-3 and graphically in Figure B-3.

Another concern is the effect of the foam component temperature on foamability and properties. To evaluate this we mixed and foamed temperature conditioned foam components. In this test the components were heated or cooled in an environmental chamber. The conditioned components were then mixed and poured at ambient temperature. The results of these tests are reported in Table B-4 and graphically in Figure B-4.

In the final use of this foam high capacity pumps will deliver the foam components to a mix chamber. With this equipment in field conditions it will be difficult to have precise control of the mix ratio. To evaluate the sensitivity of the foam system to improper mix ratio we varied the amount of "B" component used. Tests were run at the nominal mix ratio (A/B= 107/100 by weight) and with ±10g and ±20g of the "B" component. . The results of these tests are reported in Table B-5 and graphically in Figure B-5.

Results

In all cases, including the 80°F tests, water immersion slowed the foam formation. In our standard tub test the foam rises in 2.8 minutes and is tack free in 3.3 minutes. In the 80° water the rise time was 6.0 minutes and the tack free time was 6.8 minutes. As shown in Figure B-3, cooler water temperatures have a large effect. At 40° F the rise time had increased to 31.8 minutes and the tack free time to 14.6 minutes. Note the reversal in the tack free and rise times. This is caused by the initial foam formed curing before the foam underneath stops rising. In 60°F water the rise and tack free times were 8.9 minutes and 9.5 minutes respectively. Density, as determined from core samples, decreased from 2.62 lbs/ft^3 at 40°F to 1.45 lbs/ft^3 at 80°F.

As would be expected the reactivity increased and the density decreased with increasing temperature of the foam components. As shown in Figure B-4, the effect is almost linear with temperature for all variables. Over the 40 to 80°F temperature range the rise and tack free times doubled. The density showed less variation decreasing from 2.81 lbs/ft^3 at 40°F to 2.55 lbs/ft^3 at 80°F.

Varying the mix ratio, with ±20g of the "B" component had surprisingly little effect on the reactivity and foam. As shown in Figure B-5, the low "B" component test had the most effect with long tack free times. As the catalyst and physical blowing agent are in the "B" component the reactivity tended to increase even with excess "B" component. Following this trend the density decreased progressively with increasing "B" component. Although no physical property tests were run the foam did cure and appeared normal at all mix ratios evaluated.

Table B-3
Effect of Water Temperature on Foam Reactivity and Density

Water Temperature (F°)	Rise Time (Minutes)	Tack Free Time (Minutes)	Core Density (lbs/Ft^3)
41.3	No Data	14:40	2.92
40.2	36:30	14:29	2.37
40.1	27:09	14:35	2.58
40.5	**31:49**	**14:35**	**2.62**
60.0	9:30	10:35	2.55
60.8	8:08	8:24	2.16
60.7	9:00	9:30	1.81
60.5	**8:53**	**9:30**	**2.17**
80	6:30	7:35	1.72
79.9	5:44	6:38	1.36
80.1	5:45	6:08	1.27
80.0	**6:00**	**6:47**	**1.45**

Notes:

1. Approximately one half pound foam poured into 2.5 gallons water.
2. Densities obtained from 7/8" diameter core samples.
3. Foam system: North Carolina Foam Industries, NCFI-811-91.

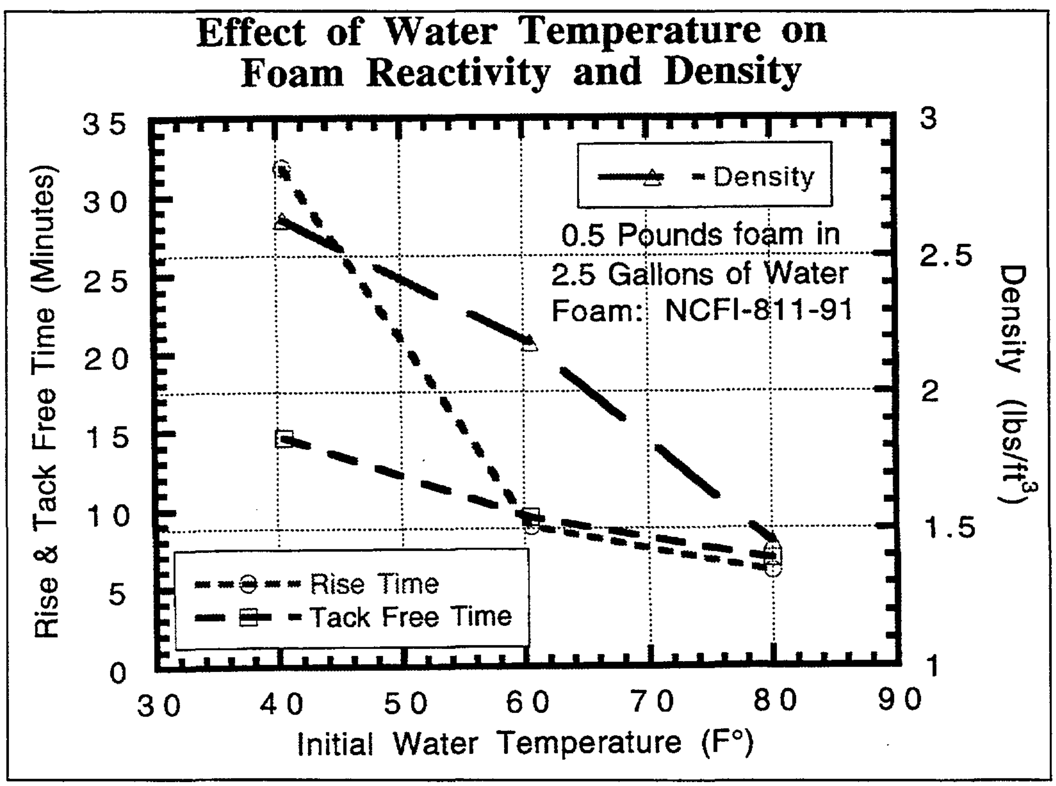


Figure B-3

Table B-4
Effect of Component Temperature on Foam Reactivity and Density

Component Temperature (F°)	Rise Time (Minutes)	Tack Free Time (Minutes)	Cup Density (lbs/Ft^3)
40	5:50	6:12	2.82
40	5:10	6:02	2.82
40	5:12	6:18	2.78
Average	**5:24**	**6:10**	**2.81**
60	3:40	4:48	2.73
60	3:36	4:42	2.69
60	3:27	4:18	2.66
Average	**3:34**	**4:36**	**2.69**
80	2:29	3:03	2.54
880	2:27	3:09	2.56
80	2:29	2:58	2.54
Average	**2:28**	**3:03**	**2.55**

Notes:
1. Components conditioned in environmental chamber before mixing.
2. Foams were mixed for 25 seconds and allowed to rise in a room temperature environment.
3. Amount of foam mixed: 107 g"A" + 100g "B" = 207 grams.
4. Foam system: North Carolina Foam Industries, NCFI-811-91.
5. Cup density is the foam density in a 1/2 gallon tub.

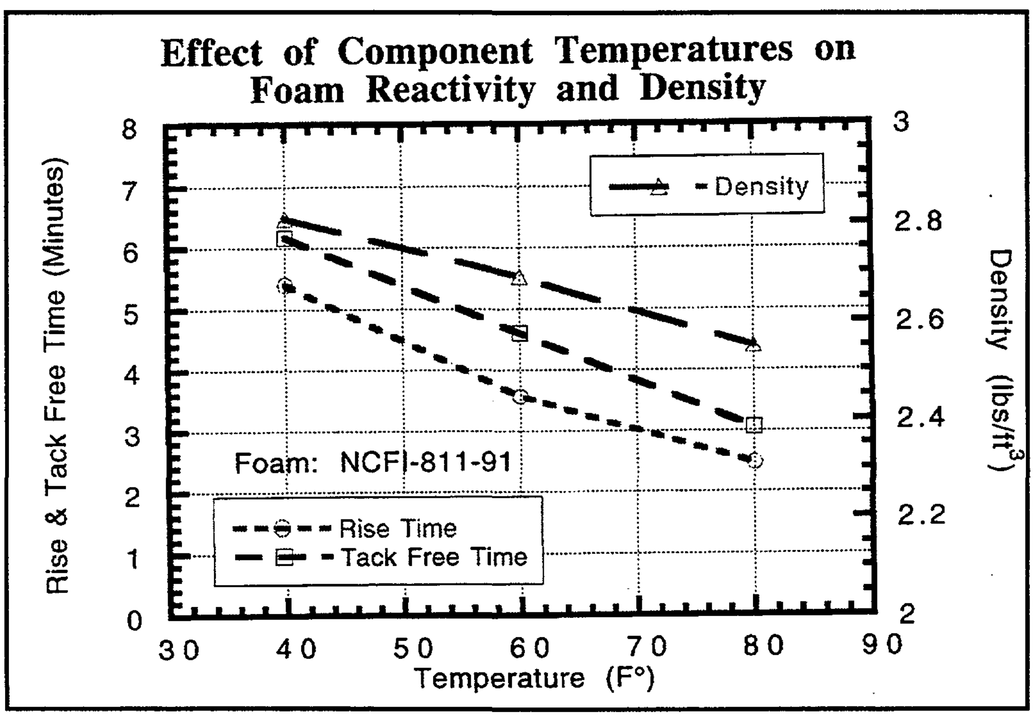


Figure B-4

Table B-5
Effect of Component Ratio on Foam Reactivity and Density

Sample	Mix Ratio (A/B)	"B" Component Deviation	Rise Time (Minutes)	Tack-free Time (Minutes)	Cup Density (lbs/ft^3)
OR-A1	1.34	-20%	3:04	4:54	3.08
OR-A2	1.34	-20%	3:14	4:27	3.10
OR-A3	1.34	-20%	3:00	4:35	3.05
Average			**3:06**	**4:38**	**3.08**
Std Dev.			0:07	0:13	0.03
OR-B1	1.19	-10%	2:53	3:31	2.81
OR-B2	1.19	-10%	2:50	3:49	2.74
OR-B3	1.19	-10%	2:53	3:32	2.80
Average			**2:52**	**3:37**	**2.78**
Std Dev.			0:01	0:10	0.03
OR-C1	1.07	0%	2:53	3:28	2.58
OR-C2	1.07	0%	2:49	3:06	2.60
OR-C3	1.07	0%	2:47	3:15	2.58
Average			**2:49**	**3:16**	**2.59**
Std Dev.			0:03	0:11	0.01
OR-D1	0.97	10%	2:57	3:10	2.47
OR-D2	0.97	10%	2:52	3:04	2.48
OR-D3	0.97	10%	2:48	3:15	2.45
Average			**2:52**	**3:09**	**2.47**
Std. Dev.			0:04	0:05	0.02
OR-E1	0.89	20%	2:52	3:00	2.39
OR-E2	0.89	20%	2:47	2:58	2.39
OR-E3	0.89	20%	2:46	2:59	2.36
Average			**2:48**	**2:59**	**2.38**
Std Dev.			0:03	0:01	0.01

Notes: 1. Cup density is the foam density in a 1/2 gallon tub.
2. Foam components were mixed for 25 seconds before pouring.
3. Foam System: North Carolina Foam Industries NCFI-811-91

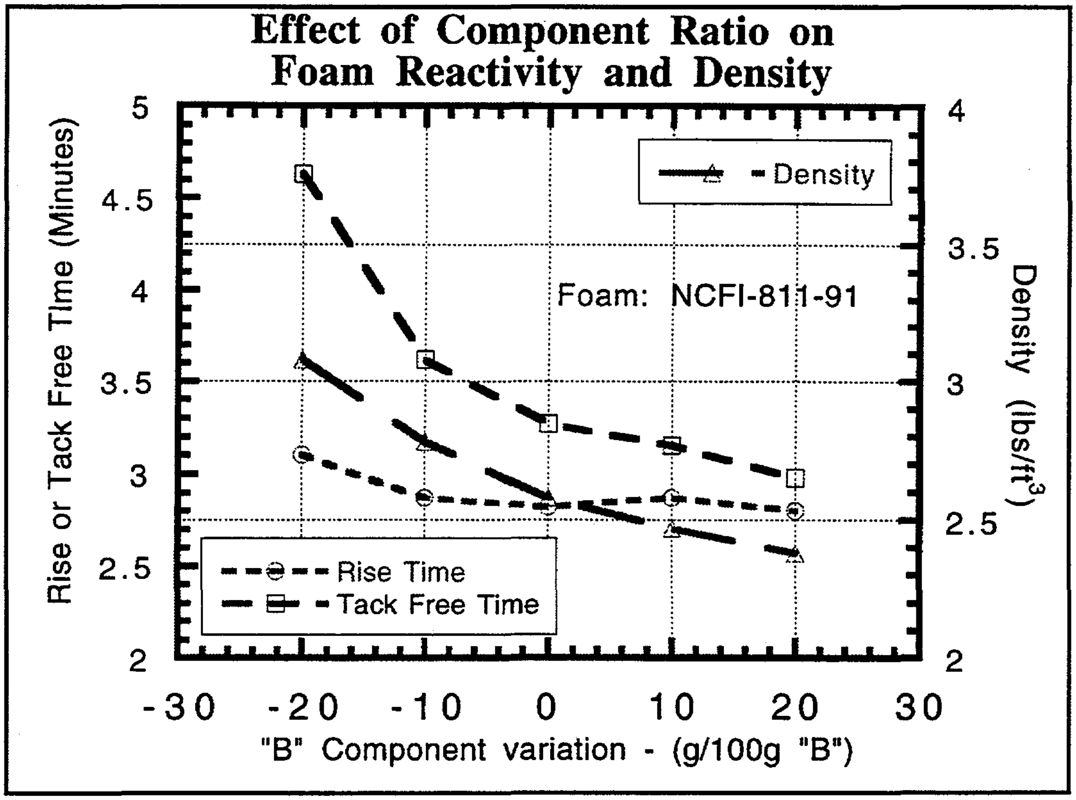


Figure B-5

Conclusions

Whatever we did it foamed! None of the environments evaluated stopped the foam from foaming. The most deleterious was the water immersion at 40°F. This caused large increases in the rise and tack free time. The 80°F water temperature reduced the density to 1.45 lbs/ft^3. This could cause problems as the foam could be too weak to support the vehicle weight. Only larger scale field tests will tell if this is a real problem.

Varying the component temperature had more effect on the rise and tack free time than the density. Probably of more concern will be changes in the foam machine performance caused by temperature induced viscosity changes in the components.

Using too little or to much "B" component had the expected effect on reactivity and foam density. In spite of these variations the foam appeared usable at all of the ratios evaluated.

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: February 29, 1996

to: R. L. Woodfin, 2522

from: P. B. Rand & B. G. Hance, 1811

subject: Foams for Barrier Crossing - Evaluation of Intumescent Foam, Exotherm Temperatures, and Foam-to-Foam Bonding

Reference: Memo, "Foams For Barrier Crossing - Effect of Water Temperature, Component Temperature, and Component Ratio on Foam Reactivity and Density", January 11, 1996, from P. B. Rand, Brad Hance, 1811 to R. L. Woodfin, 9122

Summary: Concerns about the flammability of rigid foams for this application led to the evaluation of an intumescent foam for this application. Unfortunately the only known suitable intumescent foam, General Plastics FRLI-3702, did not perform well in the water immersion test. We also report exotherm temperatures on the North Carolina Foam Industries foam, NCFI 811-91 and the intumescent foam. The formation of interfacial voids, between foam pours, were investigated to prevent their formation in future foam pours.

General Plastics FRLI-3702 Evaluation.

An intumescent foam was evaluated to provide a backup foam if flammability problems developed with our primary candidate, NCFI 811-91. Intumescent foams form self-protecting carbonaceous chars when exposed to high temperatures.

The effect of the foam component temperature on foamability and properties was evaluated. In this test the components were heated or cooled in an environmental chamber to 40°F, 60°F and 80°F. The conditioned components were then mixed and poured at ambient temperature. The results of these tests are reported graphically in Figure B-6. As expected, the reactivity, as measured by the rise and tack free times, increased with increasing temperature. The density decreased. As shown in Figure B-6, the effect is almost linear with temperature for all variables. The foam quality was good for all samples.

A concern for foams used in this project is their foaming performance in water. As reported previously, the NCFI-811-91 foams very well in water. Our first test with the FRLI-3702 in room temperature water gave very poor results. In this test the mixed liquid components are poured into water and allowed to foam. As the mixed ingredients are denser than water they initially sink, rising to the surface as foaming starts. The FRLI-3702 foamed poorly and yielded brittle foams. Because of this poor performance no further foam-in-water tests were run.

One of the quality control tests we ran on the FRLI-3702 was to measure quantitatively the intumescence. In this test a 2" cube is attached to a false door of a muffle furnace. The sample is placed in an 800°C (1472°F) muffle furnace for 60 seconds. The percent change in sample length is calculated. The 2.0 lbs/ft^3 foam had an average intumescence of 88%. This is more than the 50% required by the specification on this foam.

Exotherm Temperatures - FRLI-3702 and NCFI 811-91.

Reaction exotherm temperatures were measured in 207g pours of foam into paper tubs. The exotherm temperatures were measured at four heights in the pour. The reported temperatures were recorded by the thermocouple identified as "top middle". As shown by the exotherm data plotted in Figure B-7 the "water blown" FRLI-3702 gives a significantly higher exotherm. The difference is caused by the method of making gas to generate the foam. Gas generation in FRLI-3702 is made by an exothermic chemical reaction, adding heat to the foam. The NCFI 811-91 uses a physical blowing agent which removes heat as it boils.

Foam to Foam Interfacial Bonding - NCFI-811-91

The five foot cubes made at Allied Signal/Kansas City Division were made using multiple pours. The foam formed voids between the old pour and the new pour in many of these blocks. These voids provided a weak interface that affected some of the trafficability tests. We have investigated the effect of time between pours on the interfacial voids to see if they can be eliminated. It is postulated that the voids are formed when residual foaming gas is released from the "old" foam. The results of our testing tend to confirm this hypothesis. "New" foam was poured on "old" foam with 2, 5, 15, 30 minutes; and 2, 4, and 24 hours between pours.

The interfacial bond was difficult to find when the second pour was made 2 minutes after the first. In the five minute test the void extended across an estimated 90% of the interface. The interfacial void decreased in the 15 minute pour and was almost gone in the 30 minute pour. There were no interfacial voids in the 2, 4, and 24 hour pours. We conclude that interfacial voids can be minimized by pouring foam immediately on rising foam or waiting at least 30 minutes between pours. In cold weather it may be necessary to wait longer than 30 minutes.

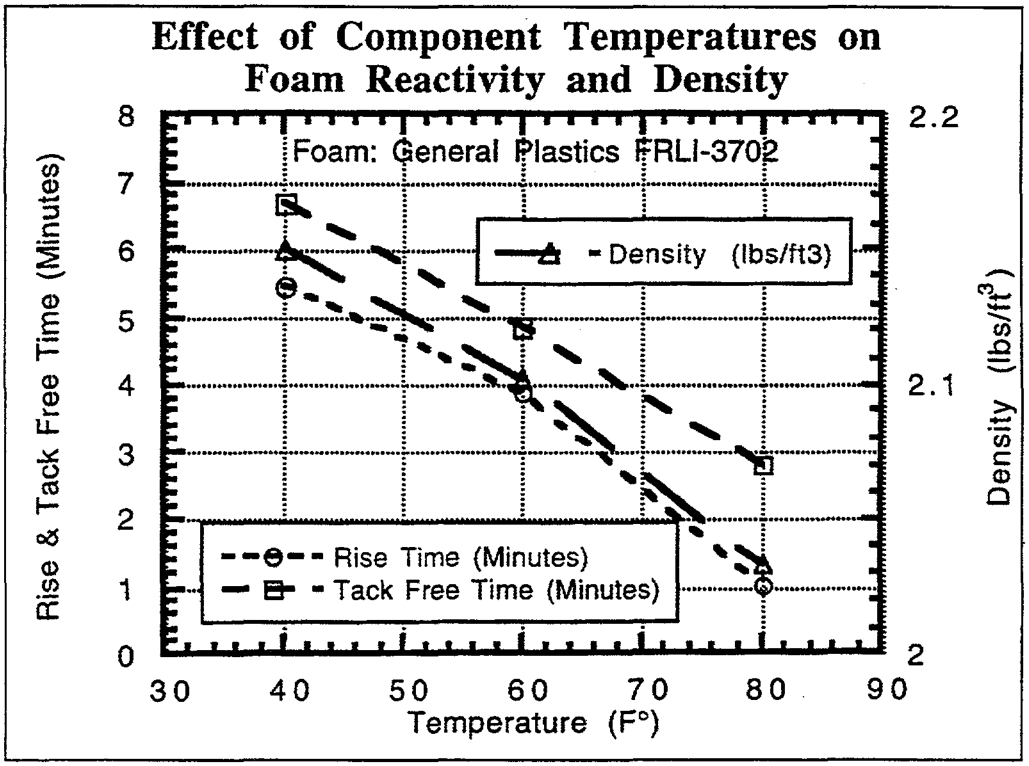


Figure B-6

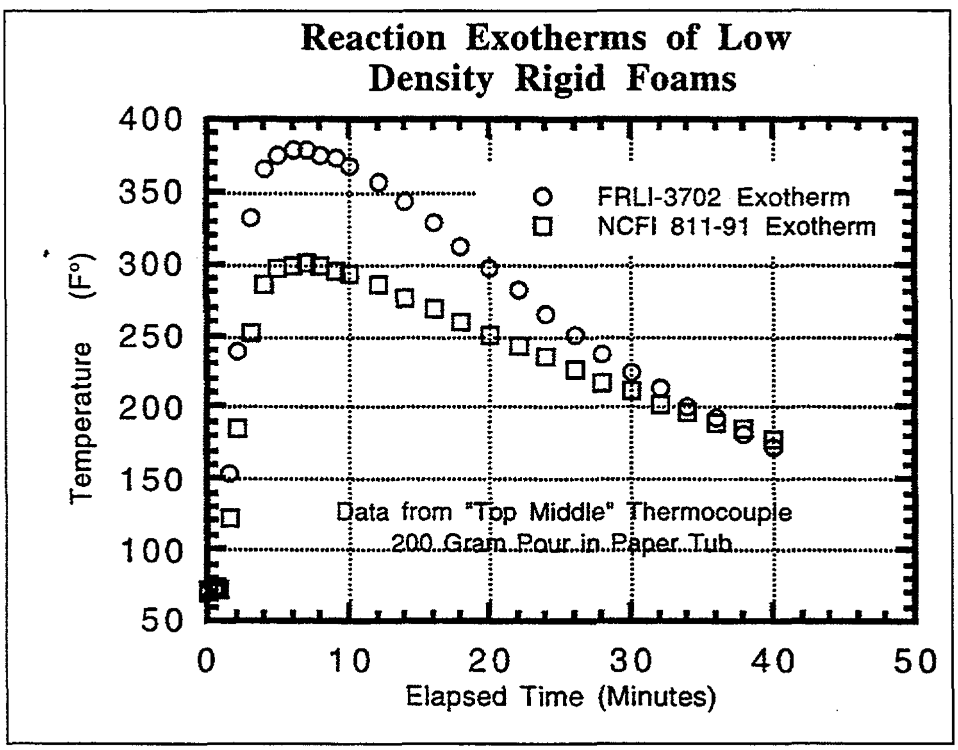


Figure B-7

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-0367

date: March 15, 1996

to: R. L. Woodfin, 2522, MS 0860

from: P. B. Rand, B. G. Hance, 1811, and M. E. Stavig, 1472

subject: Foams for Barrier Crossing - Mechanical Properties as a Function of Density, Temperature, and Time After Pour

References:

1. Memo, "Foams For Barrier Crossing -Effect of Water Temperature, Component Temperature, and Component Ratio on Foam Reactivity and Density," January 11, 1996, from P. B. Rand, Brad Hance, 1811 to R. L. Woodfin, 9122
2. Memo, "Foams for Barrier Crossing - Evaluation of Intumescent Foam, Exotherm Temperatures, and Foam-to-Foam Bonding," February 29, 1996, from P. B. Rand, Brad Hance, 1811 to R. L. Woodfin, 2522

Summary: To allow better engineering models of the foams selected for use to form barriers over obstacles, we have evaluated the mechanical properties of selected foams. Both an intumescent foam and our preferred foam were evaluated. Compressive strength properties were determined as a function of foam density, temperature, and time after the foam was formed.

The compressive properties of NCFI 811-91 were determined as a function of density, temperature, and time after foam formation. The compressive properties as a function of density were determined for an alternate intumescent foam, FRLI-3702. These data will be used to allow better engineering models of the foam in its intended use.

The compressive strength of rigid polyurethane foams increases rapidly with increasing density. To allow the selection of the best density for this application data were selected at three density levels. Specimens for evaluation of varying density on the compressive properties were cut from 8" x 8" x 3.2" molded foam blocks. All specimens were tested with the rise axis parallel to the test axis. The data for NCFI 811-91 at 3.0, 4.2 and 5.6 lbs/ft^3 and for FRLI-3702, at 2.0, 3.2, and 5.1 lbs/ft^3 are presented in Figures B-8 and B-9, respectively. Compressive stress data at 10, 30, and 50% strain versus density are presented in logarithmic plots in Figures B-10 and B-11. As expected, these data show a log linear relationship. Also included in Figures B-10 and B-11 is a curve calculated from a long-established stress-density model for rigid polyurethane foams [Stress(psi) = 12.77 (Density(lbs/ft^3)$^{1.42}$]. This curve shows that the NCFI 811-91 is lower in strength than a typical foam and FRLI-3702 has typical properties. Lower strength in the parallel to rise direction typically indicates the foam is less anisotropic and would have higher properties in the perpendicular to rise direction.

When rigid polyurethane foams are formed, the internal temperature rises to approximately 300°F due to the reaction exotherm. Because it is intended the use the barrier crossing soon after foam formation, the comrpessive properties were determined at selected temperatures. The compressive stress strain curves for NCFI 811-91 at 72, 150, and 300°F are presented in Figure B-12.

In an attempt to determine properties of recently made foams, we developed a simple test technique to evaluate a mechanical property at various times after foam formation. The test was done by penetrating the foam, formed in a cardboard tub, with a two-inch diameter ram. Both force and displacement were measured. A 207g pour of mixed ingredients was used to slightly overfill a cardboard tub. Approximate dimensions of the foam were 6.5 inch diameter by 8 inches high. The ram was allowed to penetrate 5 inches into the foam. The failure mechanisms in this test were complex, involving tensile failure of the skin, compression, shear, and tearing of the foam. There is also some evidence that the mechanism of failure was different in the early time tests. Because of this, the data from these tests should be considered comparative rather than absolute.

The load-deflection curves at 5.0, 1.0, 30.0, 60 minutes and 24 hours after foam formation are presented in Figure B-13. The initial slope and loads at selected deflections are presented in Figure B-14. A logarithmic plot is used simply to clearly show the large changes in load and time since foam formation. As shown in Figures B-13 and B-14, there is very little strength in 5.0 minutes, some in ten minutes, and almost full strength in 30 minutes. The increase is caused by both curing of the foam polymer and cooling.

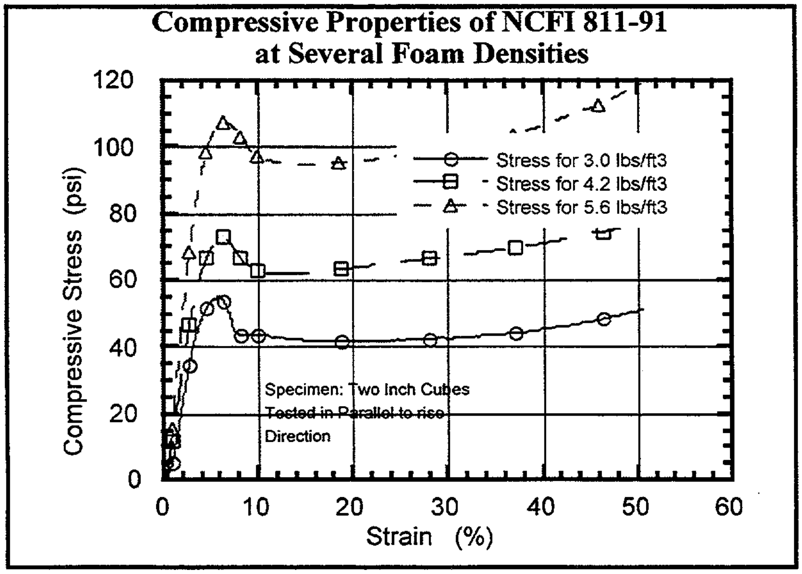


Figure B-8

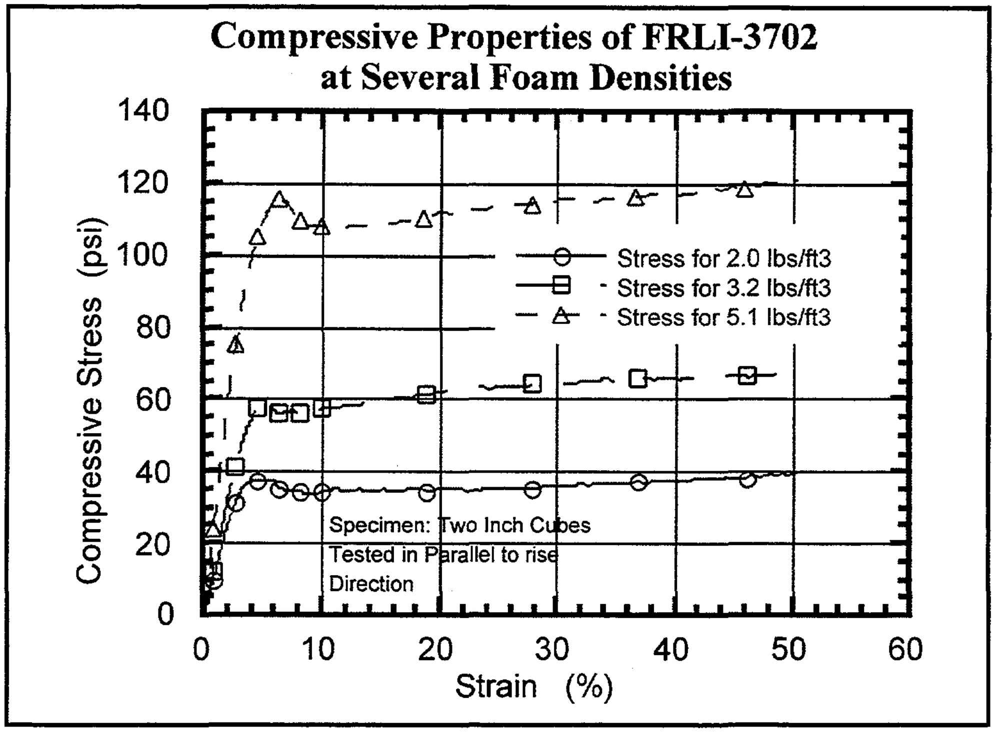


Figure B-9

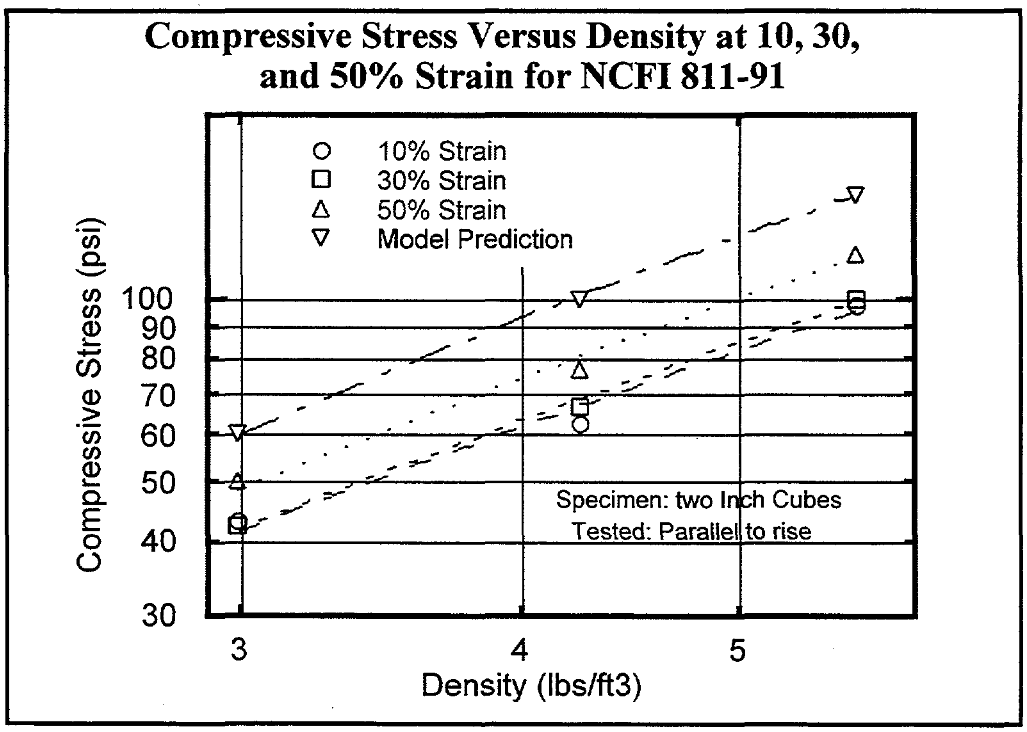


Figure B-10

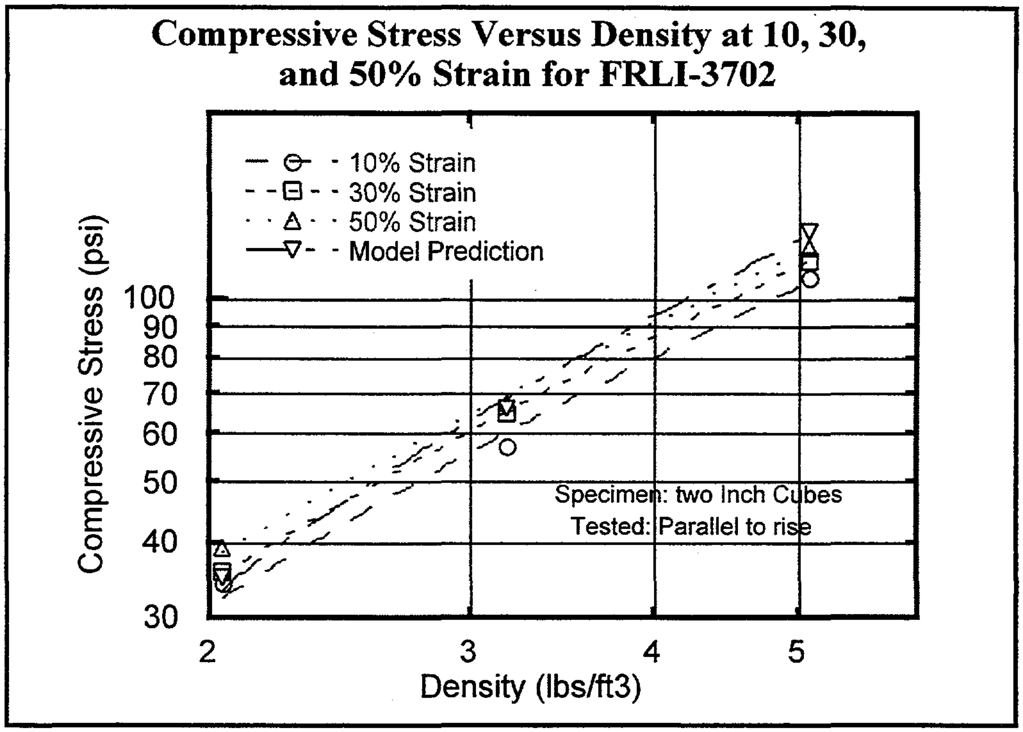


Figure B-11

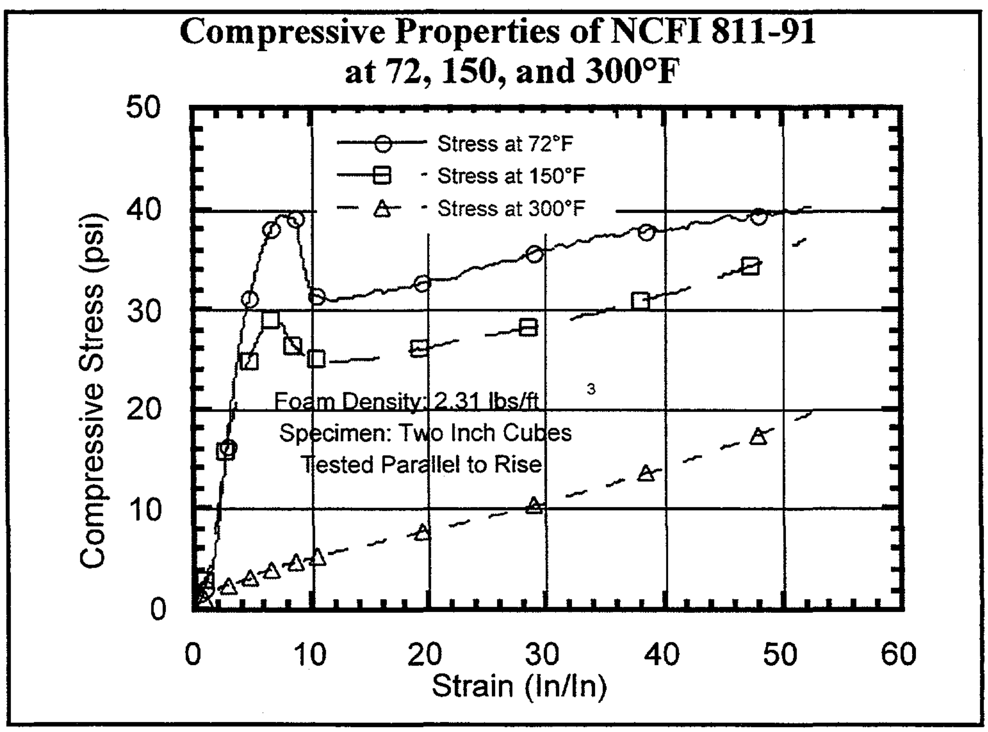


Figure B-12

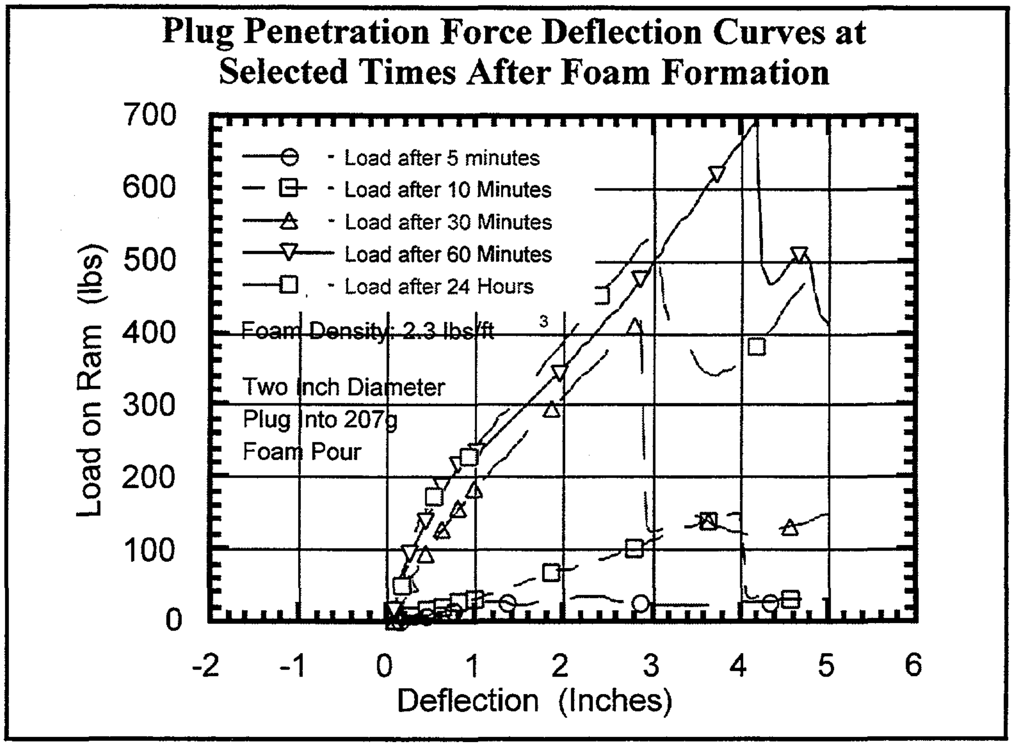


Figure B-13

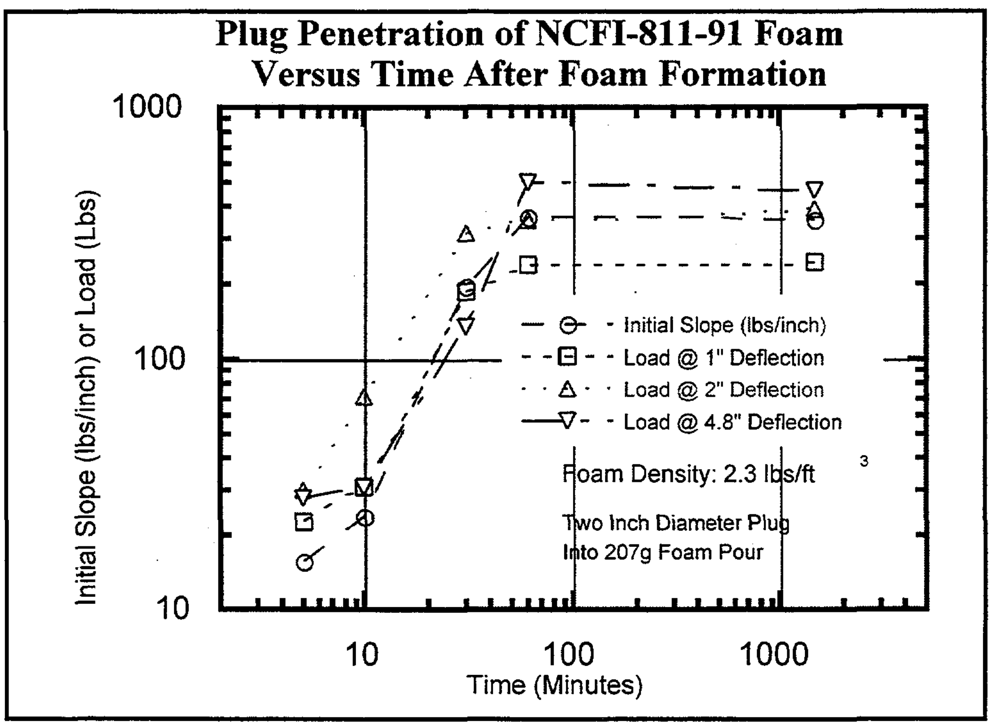


Figure B-14

EXCERPT FROM TOXICITY EVALUATION AND HAZARD REVIEW FOR RIGID FOAM

SAND93-2150 February 1994

Conclusions

The results of our evaluation indicate that the two formulations of Rigid Foam are of comparable toxicity. Fully deployed Rigid Foam is a crosslinked resin used to encapsulate an object or prevent access to an area. Under normal conditions of use and/or deployment, Rigid Foam is not expected to produce a significant health hazard. However, Rigid Foam is produced by the reaction of a toxic isocyanate component with a polyol to form the final foam product. Although the volatility of the final foam product is low enough that hazardous isocyanate vapor concentrations are unlikely during normal deployment, the possibility does exist for thermal decomposition at temperatures below ignition, resulting in the generation of toxic isocyanate vapors or other toxic vapors. In addition, a partial deployment in which the only toxic isocyanate component "A" is released would pose a significant health hazard. Furthermore, the heat generated by the polymerization of the foam could potentially cause burns to an individual in direct contact with the foaming process.

Studies indicate that the major thermal decomposition products of polyurethanes and polyisocyanates are carbon dioxide, carbon monoxide, hydrocarbons, and varoius polymer fragments. Nitrogen oxides and hydrogen cyanide are also formed, but in lesser amounts. These decomposition products are not significantly different than that of products formed from commonly accepted organic materials such as cotton, wool, polyester, and nylon. However, thermal decomposition of the foam in the absence of ignition can result in the release of toxic isocyanate gases or methylenedianiline, a known carcinogen.

The components of Rigid Foam also present a hazardous situation in the event of a partial deployment of the foam in which only the "A" component is released. The "A" component of the Rigid Foam process consists of toxic polymeric isocyanates which are severe irritants to the tissues of the mucous membranes and upper respiratory tract. Exposure to isocyanates can cause a pulmonary hypersensitivity that can result in a severe isocyanate-induced asthmatic condition. Release of the "B" component in the absence of the "A" component is not expected to result in a hazardous situation.

In addition, FREON-12 is a simple asphyxiant and is released during the foaming process. While deployment under normal conditions in a well ventilated area is not expected to pose an asphyxiation hazard due to oxygen depletion, deployment in a confined space could present a hazard. This hazardous condition is only significant if an individual is in the area during the foaming process and would not be expected under normal deployment of Rigid Foam.

Melecita M. Archuleta
William E. Stocum
Sandia National Laboratories

APPENDIX C

PENETROMETER AND SOIL COMPACTION

DROP WEIGHT CYLINDRICAL PENETROMETER

It was important to keep the soil around the foam containment fixture compacted to a stiffness approximating the stiffness of the foam block under test. Given the long, narrow footprint of the tracked vehicles, much of the total weight of the vehicle was supported by the soil on each side of the foam block. If the soil compaction did not match the foam, the foam would be subjected to either inadequate loading (stiffer soil) or excessive loading (looser soil) of the foam, resulting in misleading experimental data.

To measure the soil compaction, a standard cone penetrometer, similar to that used by the Army Corps of Engineers on unimproved roads was tried. The conical tip penetrated completely through 2 pcf foam, resulting in no reading.

C. T. Coffin, Sandia 2522, designed a blunt ended, drop weight cylindrical penetrometer that had a flat, circular end cap and was driven into the soil by one or more field-developed weights. Three disk-shaped weights of approximately 17 lb were used, falling a measured 12 inches, to provide impulse loading with energies of 17.125, 34.41, or 51.67 ft/lb. The 52 ft/lb impact was used most often. After determining the depth of penetration in both 2 and 4 pcf foam, 8 to 10 ft of the soil on each side of the experiment fixture was wet down and rolled/tamped until the stiffness of the foam was matched. Figure C-1 shows the original shop drawing of the penetrometer. Figure C-2 shows it in high desert terrain and Figure C-3 in soft soil.

Although the initial tests were conducted on the soil native to the Main Pad area, dry sand was brought in and mixed to provide a more realistic test. Figure C-4 recorded the penetration depth for a variety of soils and foam samples.

It proved possible to match the 2 pcf foam stiffness with sand to acceptable tolerance. Heavy compaction of the sand permitted matching stiffness of the 4 pcf foam after the skin was broken. Since the sand softened more rapidly than the foam as the experiment progressed, it appeared that the foam gradually acquired a greater portion of the load as the number of vehicle passes increased.

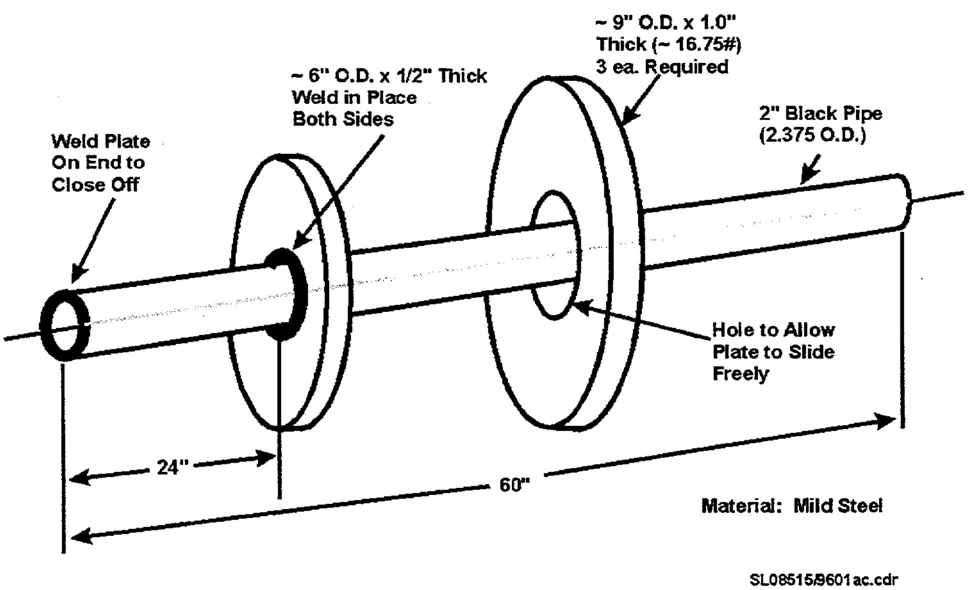


Figure C-1. Drop Weight Cylindrical Penetrometer

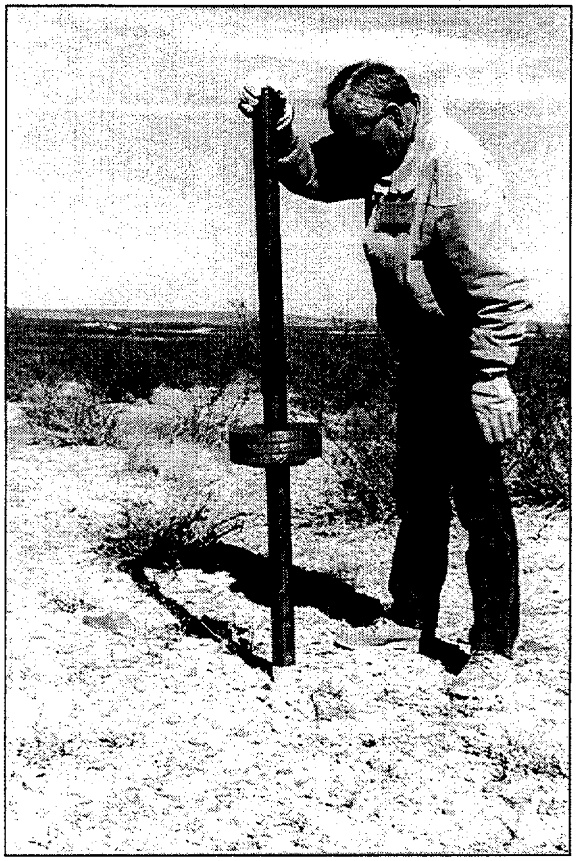


Figure C-2. Penetrometer in High Desert Terrain

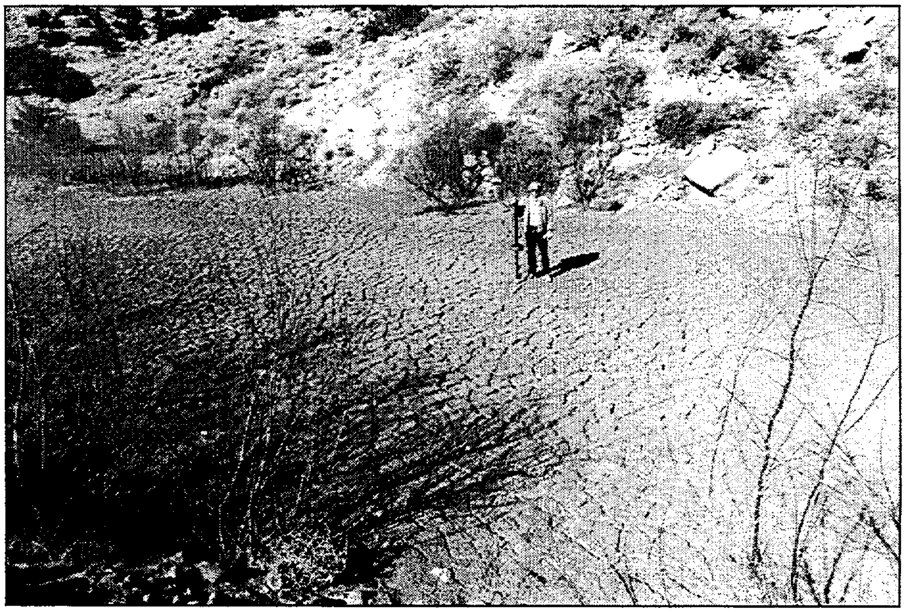


Figure C-3. Penetrometer in Soft (alluvial) Soil (This wash is the area proposed for the test "ocean.")

	Cylindrical Penetrator Samples				
Material	**Wt. A 17.125#**	**Wt. B 34.41#**	**Wt. C 51.67#**		
Packed Dirt #1	**0.375**	**0.375**	**0.5**		
Packed Dirt #2	**0.188**	**0.44**	**0.625**		
Packed Dirt #3	**0.125**	**0.44**	**0.625**		
Arroyo	**0.188**	**0.875**	**1**		
Virgin Mesa	**0.75**	**1.75**	**2.375**		
Sand	**2.75**	**3.875**	**4.875**		
Packed Sand	**1.625**	**2.125**	**2.75**		
Compacted Sand	**0.1**	**0.375**	**0.5**		
2 pcf Foam	**0.75**	**2.5**	**3.25**		
4 pcf Foam Skinned	**0**	**0.0625**	**0.188**		
4 pcf Foam Unskinned	**0.094**	**0.375**	**0.5**		

Material Comparison Using Cylindrical Impulse Penetrometer

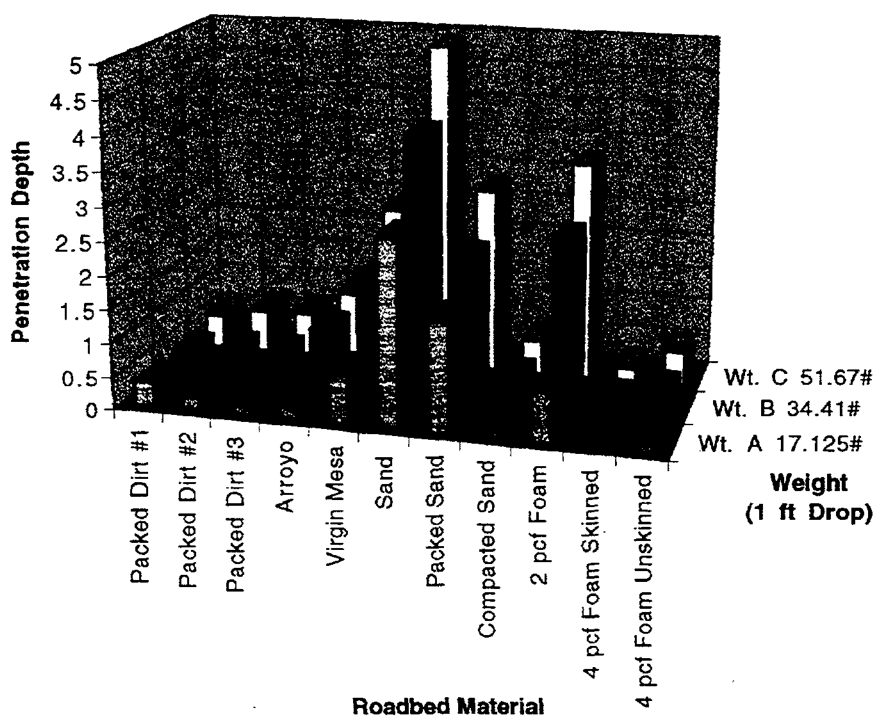


Figure C-4. Penetration in Representative Materials

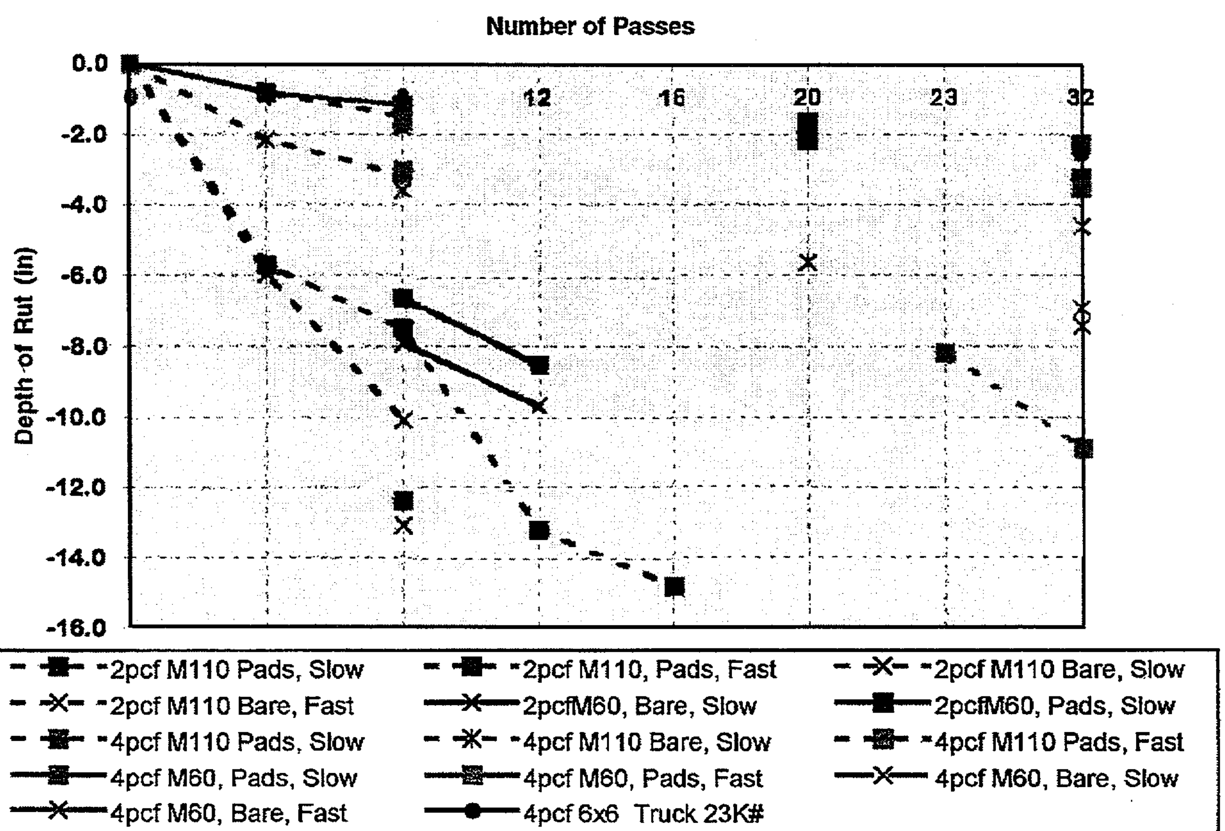
APPENDIX D

RUT PRODUCTION DATA FOR 2 AND 4 PCF FOAM

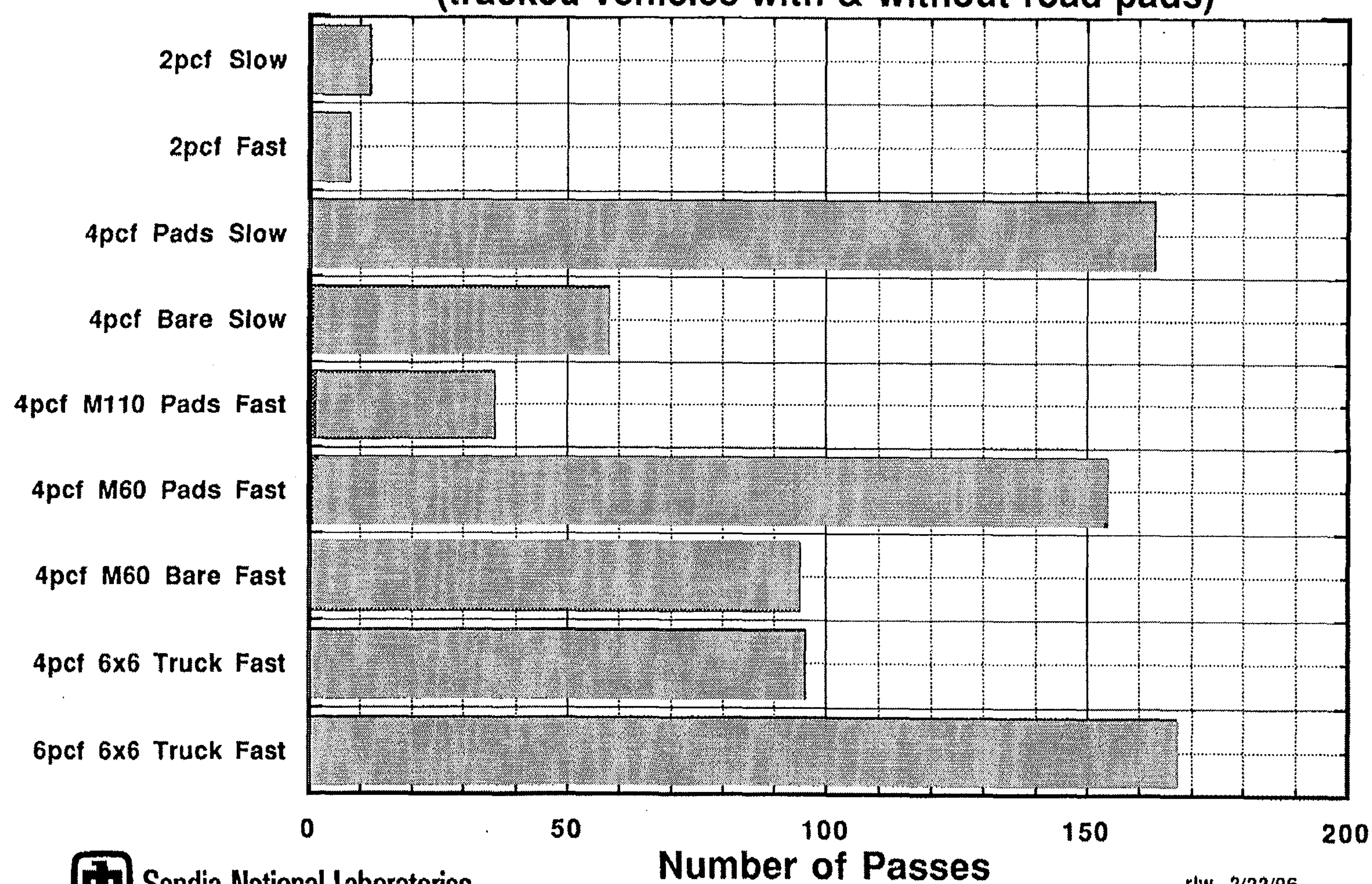
Note: This appendix reproduces the actual measured data from the Trafficability experiments. The data were entered, analyzed, and plotted using Microsoft's EXCEL spreadsheets.

Summary of Data from Trafficability Experiments on Polyurethane Foam Blocks											
									Sheet	Date	Block #
No. Passes	**0**	**4**	**8**	**12**	**16**	**20**	**23**	**32**			
2pcf M110 Pads, Slow	0.0	-5.7	-7.5	-13.2	-14.8				3	12/4/95	2-2
2pcf M110, Pads, Fast	0.0		-12.4						11	12/19/95	2-6
2pcf M110 Bare, Slow	0.0	-6.0	-10.1						2	11/30/95	2-1
2pcf M110 Bare, Fast	0.0		-13.1						12	12/20/95	2-7
2pcfM60, Bare, Slow	0.0		-7.9	-9.7					13	12/19/95	2-4
2pcfM60, Pads, Slow	0.0		-6.6	-8.5					14	12/19/95	2-5
4pcf M110 Pads, Slow	0.0	-0.8	-1.5			-2.2		-3.2	4	12/5/95	4-1
4pcf M110 Bare, Slow	0.0	-2.2	-3.2			-5.6		-7.4	6	12/7/95	4-3A
4pcf M110 Pads, Fast	0.0		-3.0				-8.2	-10.9	7	12/8/95	4-3B
4pcf M60, Pads, Slow	0.0	-0.8	-1.2			-1.7		-2.3	5	12/6/95	4-2
4pcf M60, Pads, Fast	0.0		-1.7					-3.5	8	12/8/95	4-4
4pcf M60, Bare, Slow	0.0		-3.6					-6.9	9	12/8/95	4-6
4pcf M60, Bare, Fast	0.0		-1.8					-4.6	10	12/19/95	4-7
4pcf 6x6 Truck 23K#	0.0							-2.55		1/16/96	4-8

Rut Production by Military Vehicles in Polyurethane Foams



Number of Passes Required by Military Vehicles to Produce 12" Deep Rut in Polyurethane Foam Blocks of 2 lbs/ft^3, 4 lbs/ft^3, & 6 lbs/ft^3 Density (tracked vehicles with & without road pads)



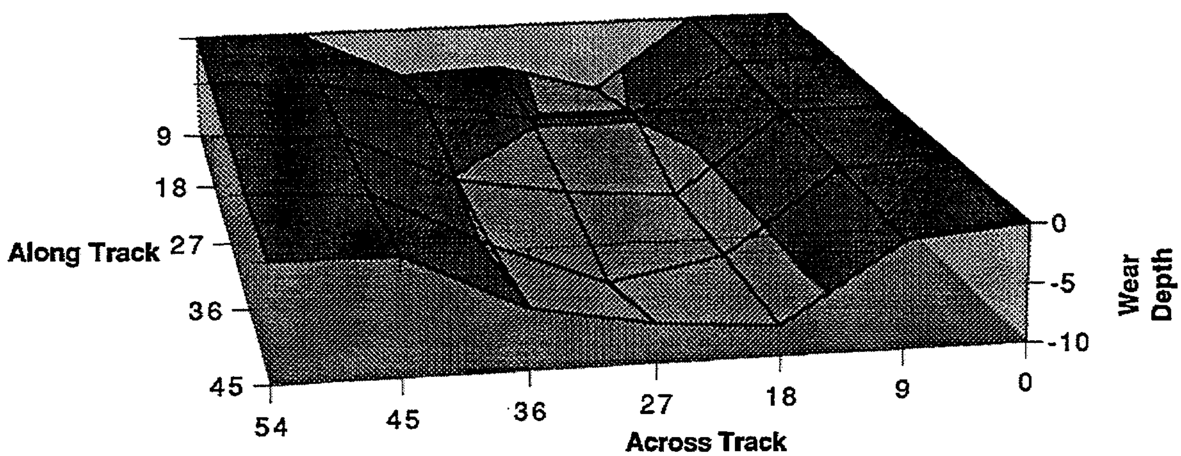
Sandia National Laboratories

rlw 2/22/96

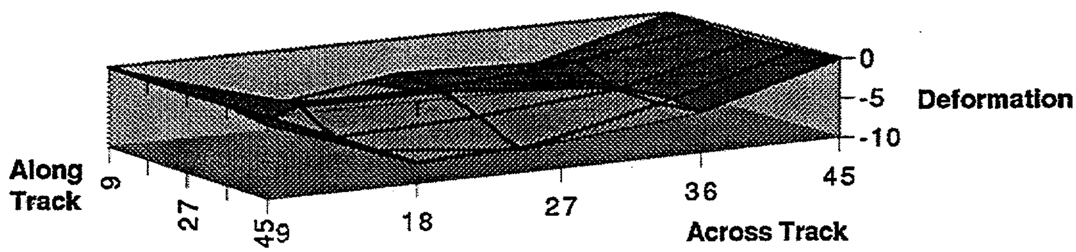
Profile Data, Block 2-1				M110 Pads OFF, Slow						
	11/30/95 00:00									
			0	9	18	27	36	45	54	
		9	0	0	-7	-4.25	-4.75	-0.125	0	
Delta (4 Passes)		18	0	-0.13	-4.75	-4.75	-3	-0.5	0	
Ave Wear=		27	0	-0.185	-7.5	-6.75	-5.125	-0.625	0	
-5.961333333		36	0	-0.25	-7.5	-9.375	-5.5	-0.5	0	
		45	0	-1	-7.5	-6.75	-4.92	-0.08	0	
			0	9	18	27	36	45	54	
		9	0	2.06	2.75	4.75	3.5	3.625	0	
Before Any		18	0	2.37	5.5	5.25	5.5	4.5	0	
		27	0	2.875	3.5	3.75	3.625	3	0	
		36	0	2.5	2.75	2.875	2.75	2.75	0	
		45	0	3.75	3.25	3.25	3.08	3	0	
			0	9	18	27	36	45	54	
		9	0	2.06	9.75	9	8.25	3.75	0	
After 4		18	0	2.5	10.25	10	8.5	5	0	
		27	0	3.06	11	10.5	8.75	3.625	0	
		36	0	2.75	10.25	12.25	8.25	3.25	0	
		45	0	4.75	10.75	10	8	3.08	0	
			0	9	18	27	36	45	54	
Before 5		9	0	1.5	8.875	9.25	6.875	3.25	0	
		18	0	1.75	9.375	9.5	7.75	3.5	0	
		27	0	4.25	10.25	9.5	8	2.875	0	
		36	0	2.25	10	9.125	7.5	2.75	0	
		45	0	3.25	10.08	9	7.75	2.5	0	
			0	9	18	27	36	45	54	
		9	0	1.5	12.92	12.75	11.75	3.25	0	
After 8		18	0	1.75	13.75	13	11.75	3.625	0	
		27	0	3.5	13.5	12.5	12	3.5	0	
		36	0	2.125	14.375	13.75	12.5	2.75	0	
		45	0	3.5	14.375	14.25	11.5	2.5	0	

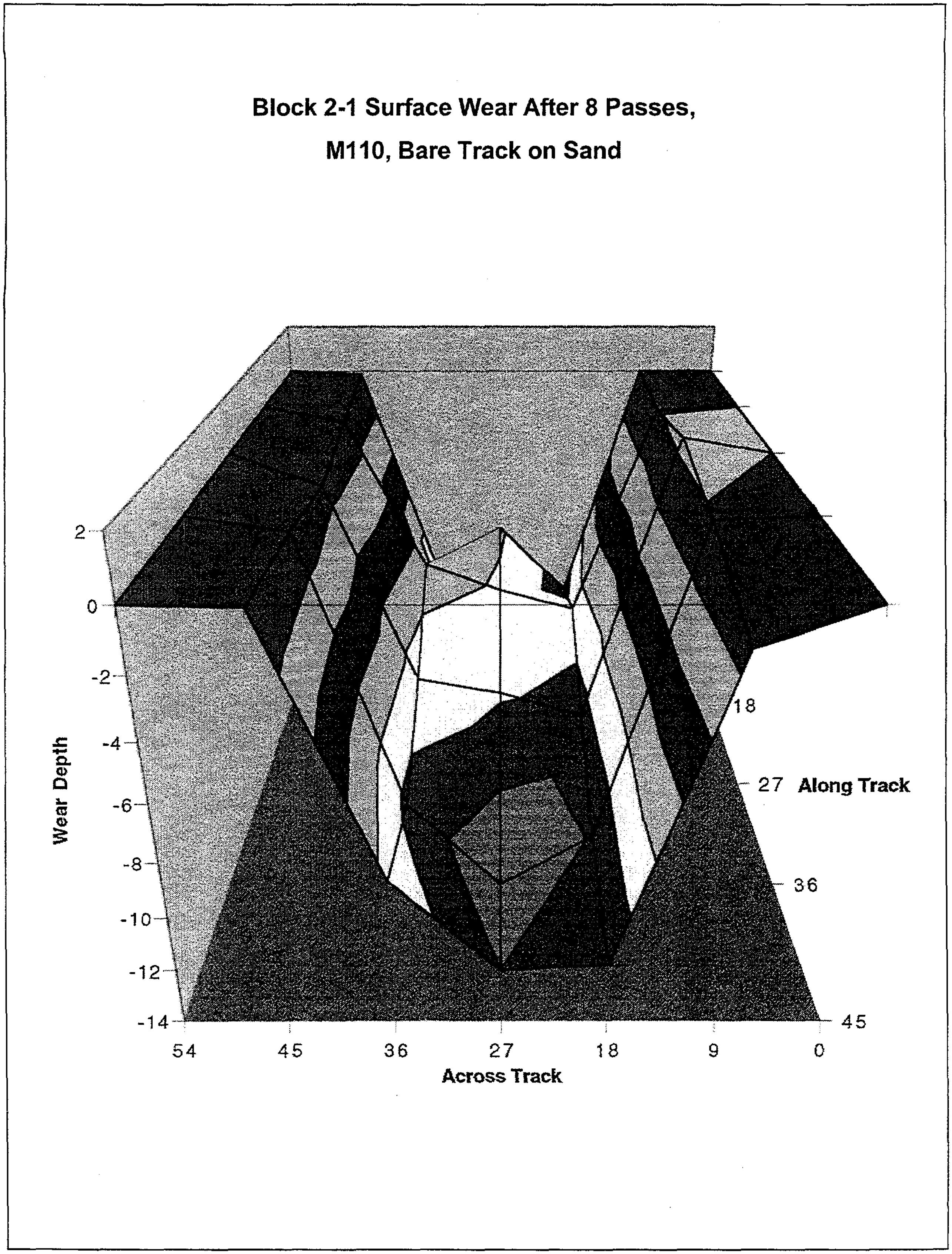
Profile Data, Block 2-1				M110 Pads OFF, Slow					
	11/30/95 00:00			continued					
			0	9	18	27	36	45	54
		9	10	10	3	5.75	5.25	9.875	10
10"-Delta		18	10	9.87	5.25	5.25	7	9.5	10
		27	10	9.815	2.5	3.25	4.875	9.375	10
		36	10	9.75	2.5	0.625	4.5	9.5	10
		45	10	9	2.5	3.25	5.08	9.92	10
			0	9	18	27	36	45	54
		9	0	0	-4.045	-3.5	-4.875	0	0
Delta 4 to 8		18	0	0	-4.375	-3.5	-4	-0.125	0
		27	0	0.75	-3.25	-3	-4	-0.625	0
		36	0	0.125	-4.375	-4.625	-5	0	0
		45	0	-0.25	-4.295	-5.25	-3.75	0	0
(8 Passes)			0	9	18	27	36	45	54
Delta 0 to 8		9	0	0	-11.045	-7.75	-9.625	-0.125	0
Ave Wear=		18	0	-0.13	-9.125	-8.25	-7	-0.625	0
-10.084		27	0	0.565	-10.75	-9.75	-9.125	-1.25	0
		36	0	-0.125	-11.875	-14	-10.5	-0.5	0
		45	0	-1.25	-11.795	-12	-8.67	-0.08	0

Block 2-1 Surface Wear After 4 Passes, M110, Bare Track

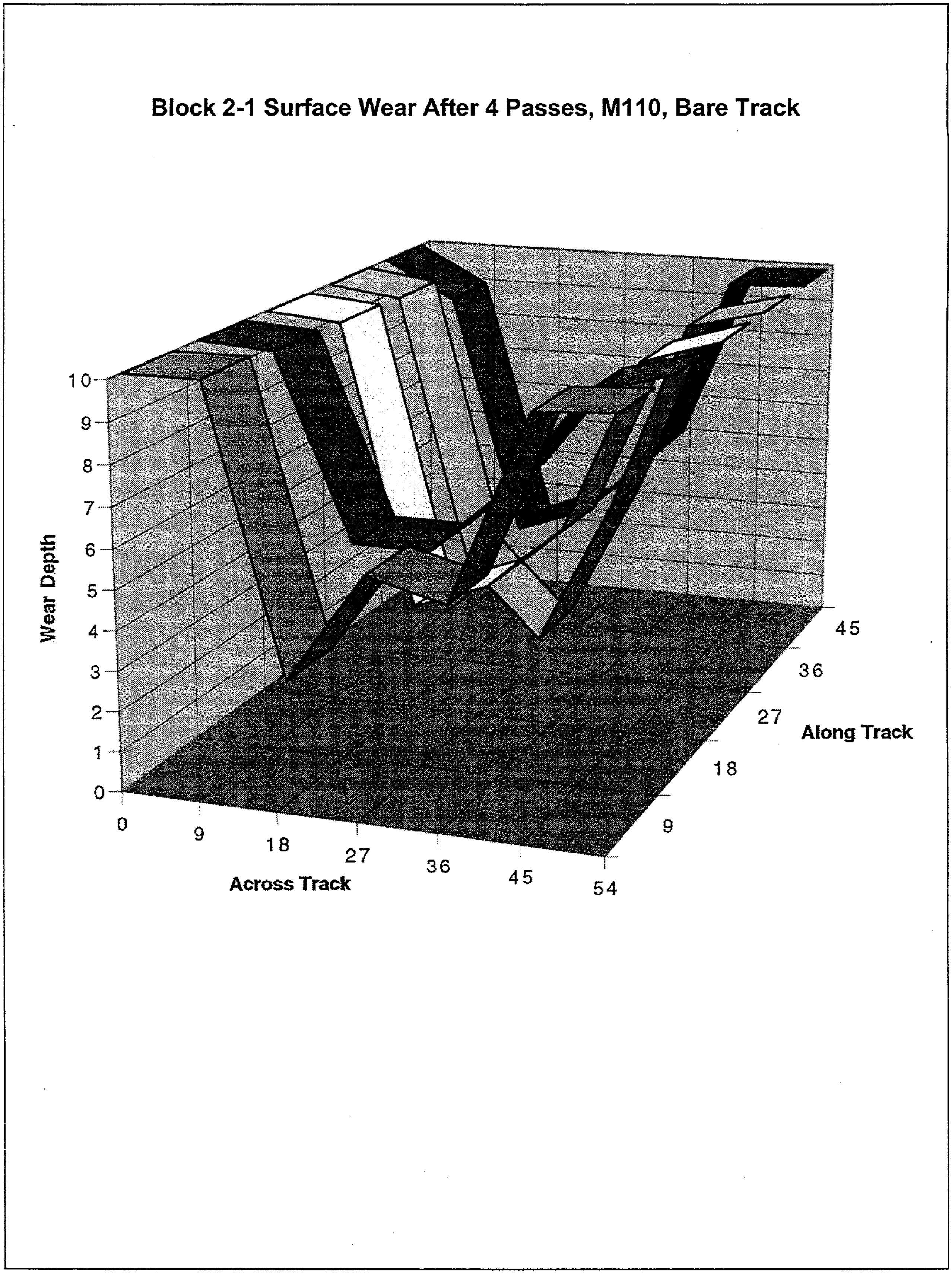


Block 2-1 Surface Deformation After 4 Passes, M110, Bare Track

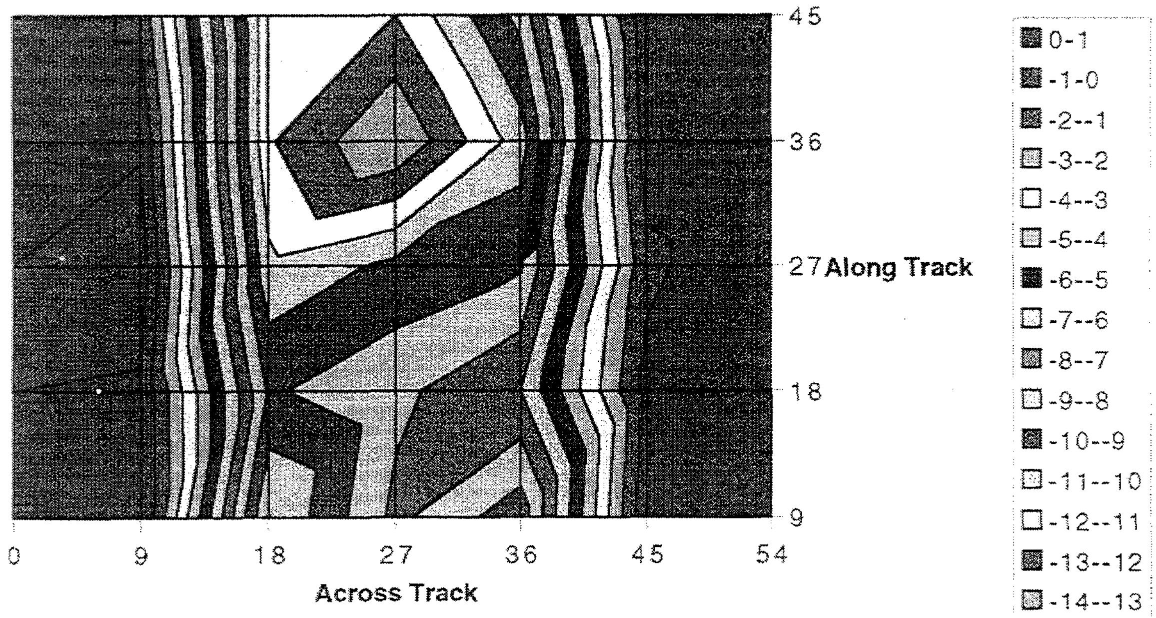




Block 2-1 Surface Wear After 8 Passes,
M110, Bare Track on Sand
Wear Depth
2
0
-2
-4
-6
-8
-10
-12
-14
54
45
36
27
18
9
0
Across Track
18
27
36
45
Along Track


Block 2-1 Surface Wear After 4 Passes, M110, Bare Track
Wear Depth
10
9
8
7
6
5
4
3
2
1
0
0
9
18
27
36
45
54
Across Track
9
18
27
36
45
Along Track

Block 2-1 Surface Wear After 8 Passes, M110, Bare Track on Sand



Profile Data, Block 2-2		M110 Pads ON, Slow							
12/4/95									
Before Test		0	9	18	27	36	45	54	
	9	0	2.5	1.5	0.75	0.75	1.5	0	
	18	0	2.75	1.25	1	0.625	0.75	0	
	27	0	3	2	1.875	0.5	0.375	0	
	36	0	3.625	2.25	1	0.75	3.25	0	
	45	0	5	3.5	2.75	3.25	3.75	0	
After 4		0	9	18	27	36	45	54	
	9	0	2.875	6.75	7.75	6.75	2	0	
	18	0	3	7.375	8	6.5	1.25	0	
	27	0	3.375	7.5	7.75	7.5	0.75	0	
	36	0	4	5.5	8	7.25	3.75	0	
	45	0	5.25	6	8	8.75	4	0	
After 8		0	9	18	27	36	45	54	
	9	0	2.875	8.5	9.5	9	2	0	
	18	0	2.875	9.25	9.875	9.5	1.25	0	Data Questionable
	27	0	3.5	7.875	10.25	9	0.75	0	
	36	0	4	7.25	9.5	9.75	3.75	0	
	45	0	5	8	9.875	9	4	0	
Before 9		0	9	18	27	36	45	54	
	9	0	1.25	5	8	7.5	0.5	0	
	18	0	1.5	5	8	8	0.25	0	
	27	0	1.625	5.25	7.5	7.5	0.625	0	
	36	0	2.25	3.25	6.875	6.875	2.25	0	
	45	0	3.625	4.75	7.625	7	2.25	0	
After 12		0	9	18	27	36	45	54	
	9	0	1.5	12.375	13	12.5	2	0	
	18	0	2	12.25	13.5	12.5	1.5	0	
	27	0	2	10.5	13.5	13	1.0625	0	
	36	0	2.5625	11.75	13.5	12.125	2.6875	0	
	45	0	4	11.0625	12.25	10	2.9375	0	
After 16		0	9	18	27	36	45	54	
	9	0	1.5	13.25	14.625	14.5	3.25	0	
	18	0	2.25	12.5	14.75	13.5	2.5	0	
	27	0	2	13.875	15.25	13.5	2	0	
	36	0	2.5625	15.125	13.25	13.625	2	0	
	45	0	3.875	14.625	13.375	12.5	2.625	0	

Profile Data, Block 2-2			M110 Pads ON, Slow					
12/4/95			continued					
		0	9	18	27	36	45	54
Delta (8 Passes)	9	0	-0.375	-7	-8.75	-8.25	-0.5	0
Before-After 8	18	0	-0.125	-8	-8.875	-8.875	-0.5	0
	27	0	-0.5	-5.875	-8.375	-8.5	-0.375	0
Ave Wear=	36	0	-0.375	-5	-8.5	-9	-0.5	0
-7.491666667	45	0	0	-4.5	-7.125	-5.75	-0.25	0
		0	9	18	27	36	45	54
Delta (4 Passes)	9	0	-0.375	-5.25	-7	-6	-0.5	0
Before-After4	18	0	-0.25	-6.125	-7	-5.875	-0.5	0
	27	0	-0.375	-5.5	-5.875	-7	-0.375	0
Ave Wear=	36	0	-0.375	-3.25	-7	-6.5	-0.5	0
-5.708333333	45	0	-0.25	-2.5	-5.25	-5.5	-0.25	0
		0	9	18	27	36	45	54
Delta (4 Passes)	9	0	-0.25	-7.375	-5	-5	-1.5	0
Before9-After12	18	0	-0.5	-7.25	-5.5	-4.5	-1.25	0
	27	0	-0.375	-5.25	-6	-5.5	-0.4375	0
Ave Wear=	36	0	-0.3125	-8.5	-6.625	-5.25	-0.4375	0
-5.7125	45	0	-0.375	-6.3125	-4.625	-3	-0.6875	0
		0	9	18	27	36	45	54
Delta (8 Passes)	9	0	-0.25	-8.25	-6.625	-7	-2.75	0
Before9-After16	18	0	-0.75	-7.5	-6.75	-5.5	-2.25	0
	27	0	-0.375	-8.625	-7.75	-6	-1.375	0
Ave Wear=	36	0	-0.3125	-11.875	-6.375	-6.75	0.25	0
-7.341666667	45	0	-0.25	-9.875	-5.75	-5.5	-0.375	0
		0	9	18	27	36	45	54
Delta (16 Passes	9	0	-0.625	-15.25	-15.375	-15.25	-3.25	0
Before9-After16	18	0	-0.875	-15.5	-15.625	-14.375	-2.75	0
+ Before-After8	27	0	-0.875	-14.5	-16.125	-14.5	-1.75	0
Ave Wear=	36	0	-0.6875	-16.875	-14.875	-15.75	-0.25	0
-14.83333333	45	0	-0.25	-14.375	-12.875	-11.25	-0.625	0

Profile Data, Block 4-1			M110 Pads ON, Slow					
12/5/95								
Before Test		0	9	18	27	36	45	54
	9	0	3.125	0.5	0.5	3.625	4.75	0
	18	0	4.75	1.5	0.75	4.5	5.625	0
	27	0	4.75	4.5	4	5.375	6	0
	36	0	5	5.25	5.5	4.5	3.25	0
	45	0	4	4.25	5.75	2.5	2	0
After 4 passes		0	9	18	27	36	45	54
	9	0	4	0.375	2.875	4.5	4.875	0
	18	0	5.5	1.5	3.25	4.75	5.5	0
	27	0	4.875	4	4.625	6.5	6.3125	0
	36	0	5.25	5.75	5.875	5.3125	4.625	0
	45	0	4	4.625	6.125	5.0625	2.1875	0
After 8 passes		0	9	18	27	36	45	54
	9	0	3.25	0.5	5.125	5	5	0
	18	0	4.25	4.625	5.25	4.75	5.5	0
	27	0	5.375	4.75	5.75	5.875	6	0
	36	0	4.875	5.5	6.25	5.75	5.25	0
	45	0	4.25	4.75	5.875	5.5	2.625	0
After 20 passes		0	9	18	27	36	45	54
	9	0	4.75	0.875	7.5	6.5	5.5	0
	18	0	5.6875	2.25	7.25	6.625	5.875	0
	27	0	4.25	5.1875	7	6.125	6	0
	36	0	5.25	5.875	6.3125	6.5625	3	0
	45	0	4.0625	4.125	6.75	6.75	1.9036	0
After 32 passes		0	9	18	27	36	45	54
	9	0	3.25	0.75	8.875	9	5	0
	18	0	3.75	4.25	8.5	8	5.75	0
	27	0	4.875	4.25	8.625	8	6	0
	36	0	5.25	5.5	7.5	8.5	5	0
	45	0	4.125	4.75	7.5	7.5	2.5	0

Profile Data, Block 4-1			M110 Pads ON, Slow					
12/5/95								
Delta 4 passes		0	9	18	27	36	45	54
	9	0	-0.875	0.125	-2.375	-0.875	-0.125	0
Average Wear=	18	0	-0.75	0	-2.5	-0.25	0.125	0
-0.808333333	27	0	-0.125	0.5	-0.625	-1.125	-0.3125	0
	36	0	-0.25	-0.5	-0.375	-0.8125	-1.375	0
	45	0	0	-0.375	-0.375	-2.5625	-0.1875	0
Delta 8 passes		0	9	18	27	36	45	54
	9	0	-0.125	0	-4.625	-1.375	-0.25	0
Average Wear=	18	0	0.5	-3.125	-4.5	-0.25	0.125	0
-1.483333333	27	0	-0.625	-0.25	-1.75	-0.5	0	0
	36	0	0.125	-0.25	-0.75	-1.25	-2	0
	45	0	-0.25	-0.5	-0.125	-3	-0.625	0
Delta 20 passes		0	9	18	27	36	45	54
	9	0	-1.625	-0.375	-7	-2.875	-0.75	0
Average Wear=	18	0	-0.9375	-0.75	-6.5	-2.125	-0.25	0
-2.179166667	27	0	0.5	-0.6875	-3	-0.75	0	0
	36	0	-0.25	-0.625	-0.8125	-2.0625	0.25	0
	45	0	-0.0625	0.125	-1	-4.25	0.0964	0
Delta 32 passes		0	9	18	27	36	45	54
	9	0	-0.125	-0.25	-8.375	-5.375	-0.25	0
Average Wear=	18	0	1	-2.75	-7.75	-3.5	-0.125	0
-3.233333333	27	0	-0.125	0.25	-4.625	-2.625	0	0
	36	0	-0.25	-0.25	-2	-4	-1.75	0
	45	0	-0.125	-0.5	-1.75	-5	-0.5	0

Profile Data, Block 4-2			M60 Pads ON, Slow					
12/6/95								
Before Test		0	9	18	27	36	45	54
	9	0	6.1875	5.125	4.25	1.75	0.75	0
	18	0	2.125	4.4375	4.25	1.625	0.375	0
	27	0	0.1875	0.5	4	3.375	2.125	0
	36	0	1.5	1	6	5.5	4.75	0
	45	0	6.1875	5.5	6	5.375	5.625	0
After 4 Passes		0	9	18	27	36	45	54
	9	0	7	6.25	4.5	4.625	1	0
	18	0	1.5	5.5	5	4.625	1.25	0
	27	0	0.1875	4.5	4.25	4.5	3.5	0
	36	0	2.375	6	5	6.125	5.75	0
	45	0	6	7.125	5.875	5.125	5.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	6.75	6.125	4.5	5.375	1.5	0
	18	0	2.625	6.375	6.25	5.625	1	0
	27	0	0.625	6.375	4.75	5	2.75	0
	36	0	1.25	6.5	5.875	6.25	5.375	0
	45	0	6.5	6.125	6.625	6.25	6.25	0
After 20 Passes		0	9	18	27	36	45	54
	9	0	6.5	6.0625	6.25	6.857	4.75	0
	18	0	1.9375	6.625	6.5	7.0625	4	0
	27	0	0.625	7.125	6.25	7.125	5.375	0
	36	0	1.75	7	6.375	6.875	5.875	0
	45	0	6.25	6.75	6.5	6.625	6	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	5.25	7.0625	7.3125	7.875	5.625	0
	18	0	1.875	7.5	7.8125	8.125	3.75	0
	27	0	0.625	8.25	8.125	8.5	6	0
	36	0	2.625	8.25	7.125	7.75	5.0625	0
	45	0	6	7.875	7	7	6	0

Profile Data, Block 4-2			M60 Pads ON, Slow					
12/6/95			continued					
Delta 4 passes		0	9	18	27	36	45	54
	9	0	-0.8125	-1.125	-0.25	-2.875	-0.25	0
Average Wear=	18	0	0.625	-1.0625	-0.75	-3	-0.875	0
-0.8125	27	0	0	-4	-0.25	-1.125	-1.375	0
	36	0	-0.875	-5	1	-0.625	-1	0
	45	0	0.1875	-1.625	0.125	0.25	0.375	0
Delta 8 passes		0	9	18	27	36	45	54
	9	0	-0.5625	-1	-0.25	-3.625	-0.75	0
Average Wear=	18	0	-0.5	-1.9375	-2	-4	-0.625	0
-1.1725	27	0	-0.4375	-5.875	-0.75	-1.625	-0.625	0
	36	0	0.25	-5.5	0.125	-0.75	-0.625	0
	45	0	-0.3125	-0.625	-0.625	-0.875	-0.625	0
Delta 20 passes		0	9	18	27	36	45	54
	9	0	-0.3125	-0.9375	-2	-5.107	-4	0
Average Wear=	18	0	0.1875	-2.1875	-2.25	-5.4375	-3.625	0
-1.65178	27	0	-0.4375	-6.625	-2.25	-3.75	-3.25	0
	36	0	-0.25	-6	-0.375	-1.375	-1.125	0
	45	0	-0.0625	-1.25	-0.5	-1.25	-0.375	0
Delta 32 passes		0	9	18	27	36	45	54
	9	0	0.9375	-1.9375	-3.0625	-6.125	-4.875	0
Average Wear=	18	0	0.25	-3.0625	-3.5625	-6.5	-3.375	0
-2.275	27	0	-0.4375	-7.75	-4.125	-5.125	-3.875	0
	36	0	-1.125	-7.25	-1.125	-2.25	-0.3125	0
	45	0	0.1875	-2.375	-1	-1.625	-0.375	0

Profile Data, Block 4-3			M110 Bare Track, Slow					
12/7/95								
Before Test		0	9	18	27	36	45	54
	9	0	8.75	6.4375	5.625	7.25	9.25	0
	18	0	6.9375	5.3125	4.75	5.625	7.875	0
	27	0	8.25	8.25	7.5	7.375	9.5	0
	36	0	11.5	11.1875	10.875	12.25	12.75	0
	45	0	11.25	9.875	10.75	13.25	11.25	0
After 4 Passes		0	9	18	27	36	45	54
	9	0	9.5	7.375	10.25	10	9.875	0
	18	0	7.75	6.125	10.75	11.125	8.5	0
	27	0	9.25	8.75	11.375	11	9.9375	0
	36	0	11.5	11.5625	11.875	12.5625	13.8125	0
	45	0	11.5	10	12.75	13.125	11.6875	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	9.875	7.25	12.5	12.375	9.75	0
	18	0	7.875	6.375	12.75	12.75	8.5	0
	27	0	9.3125	9	12.75	12.75	10.4375	0
	36	0	11.5	11.5	13.4375	13	13.8125	0
	45	0	11.25	9.875	13.875	13.4375	12.25	0
After 20 Passes		0	9	18	27	36	45	54
	9	0	9.75	13	14.125	13.75	9.75	0
	18	0	8	13.25	14.75	14.25	8.75	0
	27	0	9.5625	13.25	15.125	15	11.25	0
	36	0	11.5625	14.5625	15.25	14.875	12.5	0
	45	0	11.375	9.875	15.0625	14.75	12	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	9.75	15.25	15.5	15.5	9.75	0
	18	0	8	15.5	16.125	16.375	8.75	0
	27	0	9.75	15.75	16.25	16.5	10.5	0
	36	0	11.5	14.75	16.5	16.125	12.5	0
	45	0	11.375	15.25	16.5	16	12.25	0

Profile Data, Block 4-3			M110 Bare Track, Slow					
12/7/95			continued					
Delta 4 Passes		0	9	18	27	36	45	54
	9	0	-0.75	-0.9375	-4.625	-2.75	-0.625	0
Average Wear=	18	0	-0.8125	-0.8125	-6	-5.5	-0.625	0
-2.154166667	27	0	-1	-0.5	-3.875	-3.625	-0.4375	0
	36	0	0	-0.375	-1	-0.3125	-1.0625	0
	45	0	-0.25	-0.125	-2	0.125	-0.4375	0
Delta 8 Passes		0	9	18	27	36	45	54
	9	0	-1.125	-0.8125	-6.875	-5.125	-0.5	0
Average Wear=	18	0	-0.9375	-1.0625	-8	-7.125	-0.625	0
-3.154166667	27	0	-1.0625	-0.75	-5.25	-5.375	-0.9375	0
	36	0	0	-0.3125	-2.5625	-0.75	-1.0625	0
	45	0	0	0	-3.125	-0.1875	-1	0
Delta 20 Passes		0	9	18	27	36	45	54
	9	0	-1	-6.5625	-8.5	-6.5	-0.5	0
Average Wear=	18	0	-1.0625	-7.9375	-10	-8.625	-0.875	0
-5.6375	27	0	-1.3125	-5	-7.625	-7.625	-1.75	0
	36	0	-0.0625	-3.375	-4.375	-2.625	0.25	0
	45	0	-0.125	0	-4.3125	-1.5	-0.75	0
Delta 32 Passes		0	9	18	27	36	45	54
	9	0	-1	-8.8125	-9.875	-8.25	-0.5	0
Average Wear=	18	0	-1.0625	-10.1875	-11.375	-10.75	-0.875	0
-7.4375	27	0	-1.5	-7.5	-8.75	-9.125	-1	0
	36	0	0	-3.5625	-5.625	-3.875	0.25	0
	45	0	-0.125	-5.375	-5.75	-2.75	-1	0

Profile Data, Block 4-3, Bottom Half		M110Pads, Full Speed (18 mph)						
12/8/95								
Before Test		0	9	18	27	36	45	54
	9	0	11.5	10.9375	10.625	10.25	9.75	0
	18	0	11.75	11.5	11	10.625	10.375	0
	27	0	12.625	12.3125	12.125	12.125	12.25	0
	36	0	13	12.75	12.625	12.625	12.5	0
	45	0	13.125	12.9375	12.688	12.438	12.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	13.5	15.75	15.125	10.5	10	0
	18	0	16.25	16.75	15.75	11	10.313	0
	27	0	16.5	17.25	16.375	12.5	12.5	0
	36	0	16.563	17.4375	16.625	12.563	12.563	0
	45	0	15.563	16.4344	15.125	12.5	12.25	0
After 23 Passes		0	9	18	27	36	45	54
	9	0	15.875	19.25	18.75	17.625	10	0
	18	0	18.125	20	20.25	19.625	10.125	0
	27	0	20	21.25	21.125	20.75	12	0
	36	0	19	21	22	21.25	12.875	0
	45	0	23.5	21	21.875	21.25	12.5	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-2	-4.8125	-4.5	-0.25	-0.25	0
Average Wear=	18	0	-4.5	-5.25	-4.75	-0.375	0.0625	0
-3.02484375	27	0	-3.875	-4.9375	-4.25	-0.375	-0.25	0
	36	0	-3.5625	-4.6875	-4	0.0625	-0.0625	0
	45	0	-2.4375	-3.49688	-2.4375	-0.0625	0	0
Delta After 23 Passes		0	9	18	27	36	45	54
	9	0	-4.375	-8.3125	-8.125	-7.375	-0.25	0
Average Wear=	18	0	-6.375	-8.5	-9.25	-9	0.25	0
-8.196875	27	0	-7.375	-8.9375	-9	-8.625	0.25	0
	36	0	-6	-8.25	-9.375	-8.625	-0.375	0
	45	0	-10.375	-8.0625	-9.1875	-8.8125	-0.25	0

Profile Data, Block 4-3, Bottom Half		M110Pads, Full Speed (18 mph)						
12/8/95			continued					
Before 24th Pass		0	9	18	27	36	45	54
	9	0	7.5	9.875	10.5	9.5	1.875	0
	18	0	7.25	11.375	12.375	11.25	2.5	0
	27	0	11.25	12.75	12.313	12.375	4	0
	36	0	10.25	12.375	13.25	12.25	4	0
	45	0	14.25	12.875	12.75	12.125	3.625	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	7	13.5	16	14.75	4.25	0
	18	0	9.125	15.5	16.75	15.5	3.75	0
	27	0	11	16.5625	17.188	15.625	3.875	0
	36	0	10.125	15.375	16.313	15.188	3.75	0
	45	0	13.063	14.5	15.125	14.375	3.25	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	0.5	-3.625	-5.5	-5.25	-2.375	0
Average Wear=	18	0	-1.875	-4.125	-4.375	-4.25	-1.25	0
-3.8	27	0	0.25	-3.8125	-4.875	-3.25	0.125	0
	36	0	0.125	-3	-3.0625	-2.9375	0.25	0
	45	0	1.1875	-1.625	-2.375	-2.25	0.375	0
Total Wear After 32 Passes		0	9	18	27	36	45	54
	9	0	-3.875	-11.9375	-13.625	-12.625	-2.625	0
Average Wear=	18	0	-8.25	-12.625	-13.625	-13.25	-1	0
-10.903125	27	0	-7.125	-12.75	-13.875	-11.875	0.375	0
	36	0	-5.875	-11.25	-12.438	-11.563	-0.125	0
	45	0	-9.1875	-9.6875	-11.563	-11.063	0.125	0

Profile Data, Block 4-4		M60 Pads, Full Speed (12 mph)							
12/8/95									
Before Test		0	9	18	27	36	45	54	
	9	0	17.875	19	17.5	17	17.25	0	
	18	0	17.5	20.25	18.125	17.5	17.25	0	Data corrected in E6
	27	0	21.5	21	20.5	18.375	17.5	0	
	36	0	21.5	20.75	20.875	18.5	17.5	0	
	45	0	19	18.375	19	18.75	17.5	0	Data corrected in G9
After 8 Passes		0	9	18	27	36	45	54	
	9	0	17.5	19.375	19.25	20	20.25	0	
	18	0	22	21.1875	20	20.5	20.75	0	
	27	0	21.875	20.75	21	20.25	21	0	
	36	0	20.375	21.25	21.625	21.1875	21.125	0	
	45	0	16.1875	22.375	20.1875	20.3125	20.875	0	
After 32 Passes		0	9	18	27	36	45	54	
	9	0	21.25	22.5	22.5	22.1875	21.75	0	
	18	0	21.9375	22.125	22.25	22.75	22.5	0	
	27	0	21.5	23.25	22.25	22.5	22.75	0	
	36	0	21	22.375	22.375	22.375	22.875	0	
	45	0	21.3125	23.3125	22.75	22.625	22.9375	0	
Delta After 8 Passes		0	9	18	27	36	45	54	
	9	0	0.375	-0.375	-1.75	-3	-3	0	
Average Wear=	18	0	-4.5	-0.9375	-1.875	-3	-3.5	0	
-1.6525	27	0	-0.375	0.25	-0.5	-1.875	-3.5	0	
	36	0	1.125	-0.5	-0.75	-2.6875	-3.625	0	
	45	0	2.8125	-4	-1.1875	-1.5625	-3.375	0	
Delta After 32 Passes		0	9	18	27	36	45	54	
	9	0	-3.375	-3.5	-5	-5.1875	-4.5	0	
Average Wear=	18	0	-4.4375	-1.875	-4.125	-5.25	-5.25	0	
-3.5225	27	0	0	-2.25	-1.75	-4.125	-5.25	0	
	36	0	0.5	-1.625	-1.5	-3.875	-5.375	0	
	45	0	-2.3125	-4.9375	-3.75	-3.875	-5.4375	0	

Profile Data, Block 4-6		M60 Bare, Low Speed						
12/8/95								
Before Test		0	9	18	27	36	45	54
	9	0	16	19	17.25	19.375	19.875	0
	18	0	18.5	18	16.5	18.5	20.75	0
	27	0	17.625	15.25	16.75	18.375	19.625	0
	36	0	18.5	15.75	16.875	19	18.375	0
	45	0	15.5	18.375	18.75	19.5	18.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	19.75	21.25	21	21.25	21.25	0
	18	0	19.625	21.5625	21.75	22.25	22.625	0
	27	0	20.5	22.25	22.75	20.5625	21.625	0
	36	0	20.25	21.75	22.5	21.75	20.25	0
	45	0	20	21.75	21.75	21	19.625	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	24.125	24.4375	24.5625	22.4375	21.25	0
	18	0	24.75	25.3125	25	23.75	22.875	0
	27	0	25.1875	25.5	25.25	23.875	21.75	0
	36	0	25.5	25.5	25.25	23.875	19.75	0
	45	0	25.25	24.75	24.5625	22.9375	19.5	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-3.75	-2.25	-3.75	-1.875	-1.375	0
Average Wear=	18	0	-1.125	-3.5625	-5.25	-3.75	-1.875	0
-3.59375	27	0	-2.875	-7	-6	-2.1875	-2	0
	36	0	-1.75	-6	-5.625	-2.75	-1.875	0
	45	0	-4.5	-3.375	-3	-1.5	-1.375	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	-8.125	-5.4375	-7.3125	-3.0625	-1.375	0
Average Wear=	18	0	-6.25	-7.3125	-8.5	-5.25	-2.125	0
-6.921875	27	0	-7.5625	-10.25	-8.5	-5.5	-2.125	0
	36	0	-7	-9.75	-8.375	-4.875	-1.375	0
	45	0	-9.75	-6.375	-5.8125	-3.4375	-1.25	0

Profile Data, Block 4-7		M60 Bare, High Speed (14mph)						
12/19/95								
Before Test		0	9	18	27	36	45	54
	9	0	19	17.375	16.125	18.5	16.75	0
	18	0	17.5	17	17.125	18.75	13.75	0
	27	0	16.25	16.25	15.75	17	13.625	0
	36	0	20	17.25	16	17.25	13.75	0
	45	0	17	17.375	16.25	14.75	12.375	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	19.125	19	18.375	19	17.5	0
	18	0	18.125	19	18.5	19	17	0
	27	0	18.5	19	18.25	19	17.625	0
	36	0	20.5	18.75	17.75	18	16.625	0
	45	0	17.75	19.5	18.25	17.75	16.5	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	21.5	23.5	22.875	22.25	18.625	0
	18	0	21.25	23.375	22.625	21.75	18.5	0
	27	0	21	22.75	22.125	21.625	18.25	0
	36	0	20.5	22	21.75	21	17.75	0
	45	0	21.5	22	21.5	20.5	17.75	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-0.125	-1.625	-2.25	-0.5	-0.75	0
Average Wear=	18	0	-0.625	-2	-1.375	-0.25	-3.25	0
-1.825	27	0	-2.25	-2.75	-2.5	-2	-4	0
	36	0	-0.5	-1.5	-1.75	-0.75	-2.875	0
	45	0	-0.75	-2.125	-2	-3	-4.125	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	-2.5	-6.125	-6.75	-3.75	-1.875	0
Average Wear=	18	0	-3.75	-6.375	-5.5	-3	-4.75	0
-4.62	27	0	-4.75	-6.5	-6.375	-4.625	-4.625	0
	36	0	-0.5	-4.75	-5.75	-3.75	-4	0
	45	0	-4.5	-4.625	-5.25	-5.75	-5.375	0

Profile Data, Block 2-6		M110 Pads, High Speed (17mph)						
12/19/95								
Before Test		0	9	18	27	36	45	54
	9	0	6.875	8.75	8	8	4.75	0
	18	0	7.875	7.75	7.25	9	10.5	0
	27	0	7.875	8.375	7.5	9.125	11.5	0
	36	0	8.75	9.125	8.25	9.5	11.25	0
	45	0	9.375	10	9.875	13	11.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	19.25	19.75	18.5	8	4.75	0
	18	0	21.25	20.75	19.5	8.5	10.5	0
	27	0	21.25	21.75	20.5	8.5	10.5	0
	36	0	22	21.75	20.75	9.25	10.5	0
	45	0	22.25	21.5	20.5	12.5	12	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-12.375	-11	-10.5	0	0	0
Average Wear=	18	0	-13.375	-13	-12.25	0.5	0	0
-12.375	27	0	-13.375	-13.375	-13	0.625	1	0
	36	0	-13.25	-12.625	-12.5	0.25	0.75	0
	45	0	-12.875	-11.5	-10.625	0.5	-0.75	0

Profile Data, Block 2-7		M110 Bare, High Speed (17mph)					
12/20/95							
Before Test		0	9	18	27	36	45	54
	9	0	10.625	10.25	10	7.375	7.375	0
	18	0	11	10.125	6.25	5.875	6.5	0
	27	0	11	10.75	7	6.375	7	0
	36	0	10.875	10.5	10.125	8	7.875	0
	45	0	10.75	10	9.375	8.5	7.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	16	20.5	21	21	20.75	0
	18	0	16.5	22.5	22.25	22.25	20.75	0
	27	0	17	22.5	22.75	22.75	21.5	0
	36	0	16.75	21.5	21.5	22.25	19.625	0
	45	0	16.25	21.5	21.5	20.5	19.5	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-5.375	-10.25	-11	-13.625	-13.375	0
Average Wear=	18	0	-5.5	-12.375	-16	-16.375	-14.25	0
-13.09375	27	0	-6	-11.75	-15.75	-16.375	-14.5	0
	36	0	-5.875	-11	-11.375	-14.25	-11.75	0
	45	0	-5.5	-11.5	-12.125	-12	-12.25	0

Profile Data, Block 2-4		M60, Bare, Slow						
12/20/95								
Before Test		0	9	18	27	36	45	54
	9	0	16.75	17.125	17.75	18.25	19.625	0
	18	0	16.5	16.75	18.125	18	18.625	0
	27	0	18	17.125	19.125	19	19	0
	36	0	17.375	17.5	16.75	19.5	21.5	0
	45	0	17.5	18.25	17.75	21.25	21.5	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	22.125	27	25.625	25	19.375	0
	18	0	26.75	27	25.25	25.75	19.5	0
	27	0	24.375	27.375	25.25	26.25	20	0
	36	0	25.125	26.75	25.5	26.5	21.25	0
	45	0	26	27.5	26	25.75	21.75	0
After 12 Passes		0	9	18	27	36	45	54
	9	0	24.875	27	26.75	25.75	20.25	0
	18	0	28.75	28.75	27	27.875	19.25	0
	27	0	27.75	28	27.75	28	19.75	0
	36	0	28.75	28.625	28	27.5	21.25	0
	45	0	27.5	28.25	27.875	27.5	21.25	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-5.375	-9.875	-7.875	-6.75	0.25	0
Average Wear=	18	0	-10.25	-10.25	-7.125	-7.75	-0.875	0
-7.925	27	0	-6.375	-10.25	-6.125	-7.25	-1	0
	36	0	-7.75	-9.25	-8.75	-7	0.25	0
	45	0	-8.5	-9.25	-8.25	-4.5	-0.25	0
Delta After 12 Passes		0	9	18	27	36	45	54
	9	0	-8.125	-9.875	-9	-7.5	-0.625	0
Average Wear=	18	0	-12.25	-12	-8.875	-9.875	-0.625	0
-9.69375	27	0	-9.75	-10.875	-8.625	-9	-0.75	0
	36	0	-11.375	-11.125	-11.25	-8	0.25	0
	45	0	-10	-10	-10.125	-6.25	0.25	0

Profile Data, Block 2-5		M60 Pads, Slow						
12/20/95								
Before Test		0	9	18	27	36	45	54
	9	0	17.375	19	20.5	20.25	19.25	0
	18	0	18.375	20.25	21.5	21.125	19.25	0
	27	0	19.75	18.5	16	21	20.25	0
	36	0	18.875	16.25	15.125	20.75	19.5	0
	45	0	18	18.75	18	20.5	19.25	0
After 8 Passes		0	9	18	27	36	45	54
	9	0	24.5	25.625	25	21.75	19.5	0
	18	0	25.625	24.375	24.5	22.875	19.625	0
	27	0	24.75	25	24.75	21.75	20.25	0
	36	0	25.125	25.25	25.75	20	19.75	0
	45	0	25.5	25.75	24.25	21.25	19.25	0
After 12 Passes		0	9	18	27	36	45	54
	9	0	27.25	26.5	26.5	21	19.5	0
	18	0	27.5	26.75	27.5	21.5	19.375	0
	27	0	27.5	26.75	26.5	20	20.125	0
	36	0	27.625	27	26.25	20.75	19.5	0
	45	0	27.25	26.75	26.75	21	19.25	0
Delta After 8 Passes		0	9	18	27	36	45	54
	9	0	-7.125	-6.625	-4.5	-1.5	-0.25	0
Average Wear=	18	0	-7.25	-4.125	-3	-1.75	-0.375	0
-6.633333333	27	0	-5	-6.5	-8.75	-0.75	0	0
	36	0	-6.25	-9	-10.625	0.75	-0.25	0
	45	0	-7.5	-7	-6.25	-0.75	0	0
Delta After 12 Passes		0	9	18	27	36	45	54
	9	0	-9.875	-7.5	-6	-0.75	-0.25	0
Average Wear=	18	0	-9.125	-6.5	-6	-0.375	-0.125	0
-8.541666667	27	0	-7.75	-8.25	-10.5	1	0.125	0
	36	0	-8.75	-10.75	-11.125	0	0	0
	45	0	-9.25	-8	-8.75	-0.5	0	0

Profile Data, Block 4-8		6x6 Truck 20mph 23460lbs total weight						
12/20/95			Military Tires, 60 psi Inflation Pressure					
Before Test		0	9	18	27	36	45	54
	9	0	14.75	18.5	19.063	17.5	17.188	0
	18	0	18.5	20.8125	20.125	19.188	19	0
	27	0	19.5	20.5	20.5	19.5	19	0
	36	0	19.25	18.25	17.375	16.25	16.75	0
	45	0	19	17.5	16.125	15.5	16.125	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	20.875	23.25	22.375	21.125	17.125	0
	18	0	18.688	22.375	21.5	20.25	17.375	0
	27	0	19.5	20.9375	21.75	20.25	19.5	0
	36	0	19.875	20.75	20.875	20.375	19.625	0
	45	0	20.125	22.125	21	20.625	16.5	0
After 64 Passes		0	9	18	27	36	45	54
	9	0	25.5	26.5	25	23.5	17.875	0
	18	0	26.375	25.875	24.625	22.5	19.25	0
	27	0	28.625	25.75	24	20.25	19.25	0
	36	0	27	25.75	24.25	19.875	16.75	0
	45	0	25.375	26	24.375	17.625	16.375	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	-6.125	-4.75	-3.3125	-3.625	0.0625	0
Average Wear=	18	0	-0.1875	-1.5625	-1.375	-1.0625	1.625	0
-2.546875	27	0	0	-0.4375	-1.25	-0.75	-0.5	0
	36	0	-0.625	-2.5	-3.5	-4.125	-2.875	0
	45	0	-1.125	-4.625	-4.875	-5.125	-0.375	0
Delta After 64 Passes		0	9	18	27	36	45	54
	9	0	-10.75	-8	-5.9375	-6	-0.6875	0
Average Wear=	18	0	-7.875	-5.0625	-4.5	-3.3125	-0.25	0
-6.053125	27	0	-9.125	-5.25	-3.5	-0.75	-0.25	0
	36	0	-7.75	-7.5	-6.875	-3.625	0	0
	45	0	-6.375	-8.5	-8.25	-2.125	-0.25	0

Profile Data, Block 4-8		6x6 Truck 20mph 23460lbs total weight					
12/20/95		Military Tires, 60 psi Inflation Pressure					
		continued					
Before 65th Pass		0	9	18	27	36	45	54
	9	0	20.5	14.25	15	13.75	8.375	0
	18	0	19.5	15.25	14	12.5	8	0
	27	0	19	16.25	13.625	12.25	8.5	0
	36	0	20.875	15.25	13	12	5.25	0
	45	0	19.375	14.125	12.5	11	4.5	0
After 96 Passes		0	9	18	27	36	45	54
	9	0	20.75	21.375	21.188	20.5	11.188	0
	18	0	20.5	21.375	21.25	18.875	10.75	0
	27	0	19.5	21.75	21.25	19.5	8.375	0
	36	0	20.5	22.25	21.5	15.25	8.75	0
	45	0	22.125	22.25	21.375	17.125	7	0
Delta After 96 Passes		0	9	18	27	36	45	54
	9	0	-0.25	-7.125	-6.1875	-6.75	-2.8125	0
Average Wear=	18	0	-1	-6.125	-7.25	-6.375	-2.75	0
-6.804166667	27	0	-0.5	-5.5	-7.625	-7.25	0.125	0
	36	0	0.375	-7	-8.5	-3.25	-3.5	0
	45	0	-2.75	-8.125	-8.875	-6.125	-2.5	0
Total Wear After 96 Passes		0	9	18	27	36	45	54
	9	0	-11	-15.125	-12.125	-12.75	-3.5	0
Average Wear=	18	0	-8.875	-11.188	-11.75	-9.6875	-3	0
-12.08333333	27	0	-9.625	-10.75	-11.125	-8	-0.125	0
	36	0	-7.375	-14.5	-15.375	-6.875	-3.5	0
	45	0	-9.125	-16.625	-17.125	-8.25	-2.75	0

Profile Data, Block 6-1		6x6 Truck 20mph 23460lbs total weight						
2/21/96			Military Tires, 60 psi Inflation Pressure					
Before Test		0	9	18	27	36	45	54
	9	0	20.568	20.5	20.375	20.25	20.25	0
	18	0	20.75	20.5	20	20.25	20.375	0
	27	0	20.75	20.75	20.25	20.5	20.5	0
	36	0	20.75	21	20.5	20.75	20.75	0
	45	0	20.75	20.75	20.875	21	20.75	0
After 32 Passes		0	9	18	27	36	45	54
	9	0	20.625	20.75	21.625	21.5	20.5	0
	18	0	20.75	20.75	21.625	20.75	20.625	0
	27	0	20.75	20.875	21	20.875	20.875	0
	36	0	20.75	20.875	21	21.125	21	0
	45	0	20.625	20.75	22.25	21.125	21	0
After 64 Passes		0	9	18	27	36	45	54
	9	0	20.75	20.875	23.125	22.75	20.75	0
	18	0	20.75	21	22.875	22.25	21	0
	27	0	20.75	21.5	22.75	22.25	21.25	0
	36	0	20.75	21.5	22.625	22.125	21.125	0
	45	0	20.75	22.125	23	22.5	21.375	0
Delta After 32 Passes		0	9	18	27	36	45	54
	9	0	-0.0575	-0.25	-1.25	-1.25	-0.25	0
Average Wear=	18	0	0	-0.25	-1.625	-0.5	-0.25	0
-0.427875	27	0	0	-0.125	-0.75	-0.375	-0.375	0
	36	0	0	0.125	-0.5	-0.375	-0.25	0
	45	0	0.125	0	-1.375	-0.125	-0.25	0
Delta After 64 Passes		0	9	18	27	36	45	54
	9	0	-0.1825	-0.375	-2.75	-2.5	-0.5	0
Average Wear=	18	0	0	-0.5	-2.875	-2	-0.625	0
-1.259125	27	0	0	-0.75	-2.5	-1.75	-0.75	0
	36	0	0	-0.5	-2.125	-1.375	-0.375	0
	45	0	0	-1.375	-2.125	-1.5	-0.625	0

Profile Data, Block 6-1		6x6 Truck 20mph 23460lbs total weight						
2/21/96			Military Tires, 60 psi Inflation Pressure					
			continued					
After 96 Passes		0	9	18	27	36	45	54
	9	0	20.5	24	25	24	22.25	0
	18	0	20.625	24.5	25.125	23.75	21.875	0
	27	0	20.75	24	25	24	22.125	0
	36	0	20.625	23.75	24.625	23.75	21	0
	45	0	20.5	23	24.25	23.375	20.75	0
Delta After 96 Passes		0	9	18	27	36	45	54
	9	0	0.0675	-3.5	-4.625	-3.75	-2	0
Average Wear=	18	0	0.125	-4	-5.125	-3.5	-1.5	0
-3.591666667	27	0	0	-3.25	-4.75	-3.5	-1.625	0
	36	0	0.125	-2.75	-4.125	-3	-0.25	0
	45	0	0.25	-2.25	-3.375	-2.375	0	0

APPENDIX E

MEMORANDUM REPORT

INITIAL NUMERICAL RESULTS FOR THE TANK SHIELDING IDEA

David L. Alumbaugh
Gregory A. Newman

Sandia National Laboratories

Initial Numerical Results for the Tank Shielding Idea

David L. Alumbaugh
Gregory A. Newman

A series of numerical experiments have begun to determine if the magnetic signature of a tank can be shielded from an anti-tank mine by including magnetically permeable material within a foam that is sprayed over the mine field in order to let the tanks cross. This testing phase was accomplished employing a layered earth code that allows for the calculation of the electromagnetic fields anywhere that are generated in or above the earth by either an electric or magnetic dipole source. This source can be located anywhere, and the earth can have variable electrical conductivity, magnetic permeability and dielectric permitivity. Here we only consider variable permeability.

The model employed in this exercise is shown in Figure E-1. It consists of a layer of variable thickness and magnetic permeability (μ) representing the foam overlying the earth, where the electrical conductivity of both the foam and earth is set to 0.01S/m. The measurement point is always located 15cm below the earth's surface, and the magnetic dipole crudely representing the tank is located 50cm above the foam layer. The frequency employed here was 1×10^{-6} Hz, which means we are essentially operating in the static regime and can ignore the effects of dielectric permitivity in the results. The layer thickness was varied from .15m to 3m at 0.15m intervals. The magnetic permeability of the layer was varied from 1 to 39 at intervals of 2. This range was chosen in the following manner. Arbitrarily we chose 10% of the foam volume as the maximum amount of magnetic material which could be included. From Table 6 in Keller (1988, p. 36), we determined that including 10% magnetite in a rock would provide a μ of about 38.7 which we then rounded up to 39. This is a crude value that may be much different if different magnetic materials are employed, and thus we have no idea if this is too low or too high for what can actually be obtained.

Figure E-2 shows the results from this experiment. The magnetic field values are plotted in a logarithmic scale with contours at 0.2 intervals in log space. Notice that increasing the magnetic permeability from 1 to 40 drops the amplitude almost one order of magnitude, while increasing the thickness from 0 to 3m exceeds this amount. In addition, notice that as the magnetic permeability is increased, the contours begin to parallel the y axis. This indicates that the shielding effect of the layer is beginning to saturate such that further increasing μ in a linear fashion will produce only minimal reduction in the fields measured at the mine location. To cause further significant decreases in the fields would varying the permeability in a logarithmic rather than linear fashion which is physically unrealizable.

In Figure E-3 we have plotted the results as the magnetic dipole is moved from -21m to 21m over the measurement point for three different layer thicknesses of 1m, 2m and 3m. In each case we have also plotted the results that would normally be observed without the layer. This shows some interesting differences between increasing layer thickness versus increasing the permeability. Increasing the thickness tends to broaden, or low pass filter the response to a greater degree than increasing the permeability, whose main effect is simply to attenuate the response over the entire length of the profile. The low pass filtering effect of the increasing layer thickness is more evident in Figure E-4, where μ has been set to unity and to 40 and only the thickness is varied.

It must be mentioned that there are two very simplifying assumptions made in these calculations having to do with employing a dipole source of unit moment. The first is the magnitude of the dipole, which here is set to 1 Am^2, and the second is the size of the source. With regards to the first problem, the tank most likely has a moment which is much larger than 1 Am^2. However, because the response is linearly dependent on the moment, an increased moment of the tank will simply imply scaling the results presented here by that value. The second problem, which is more difficult to solve, is the shape and size of the tank; it is very likely that it cannot be well represented by a point dipole. Although we are currently examining ways to better simulate this, including the use of our finite difference code, it is a tricky problem and may take some time.

In conclusion, the results presented here have shown some very interesting effects, including magnetic permeability in a foam layer. Increasing the permeability to what we feel are reasonable amounts will only decrease the magnetic signature of the target by one order of magnitude. Increasing the thickness of the layer can not only decrease the amplitude by a greater amount but also adds a low pass filtering effect to the response. Although we feel the addition of μ into the foam is favorable, we question if the one order of magnitude decrease in signal amplitude is substantial enough to warrant including a permeable material in the foam. Thus, before proceeding much further with additional numerical simulations, we suggest that an attempt should at least be made to obtain the following information:

1. We need to know what the fusing mechanism of the anti-tank mine detects. Is it total field or the field in a given direction, and what is the sensitivity of the fuse?

2. What is the maximum magnetic permeability that can reasonably be included in the foam?

3. What is an estimate of the dipole moment of a tank?

If these questions are answered, we believe a more educated decision on whether or not to include a magnetically permeable substance within the foam can be made.

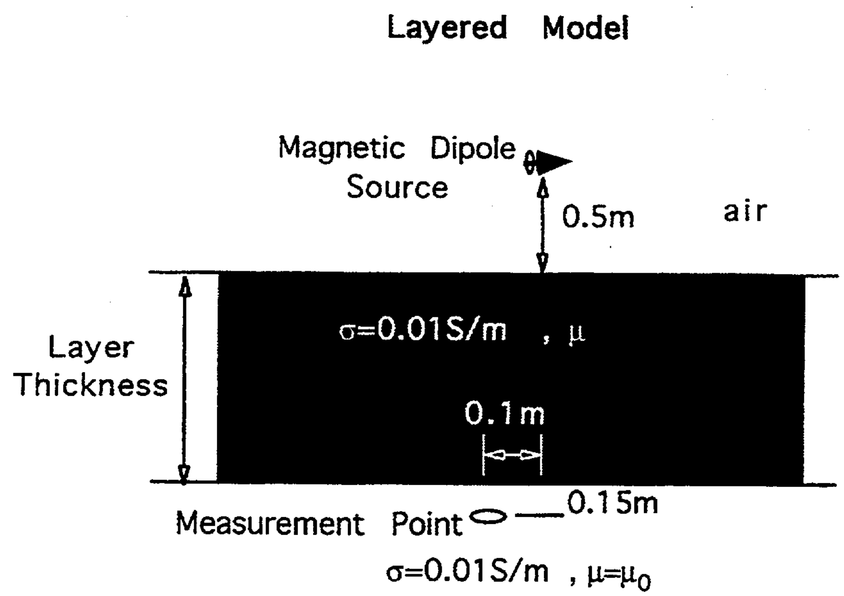


Figure E-1

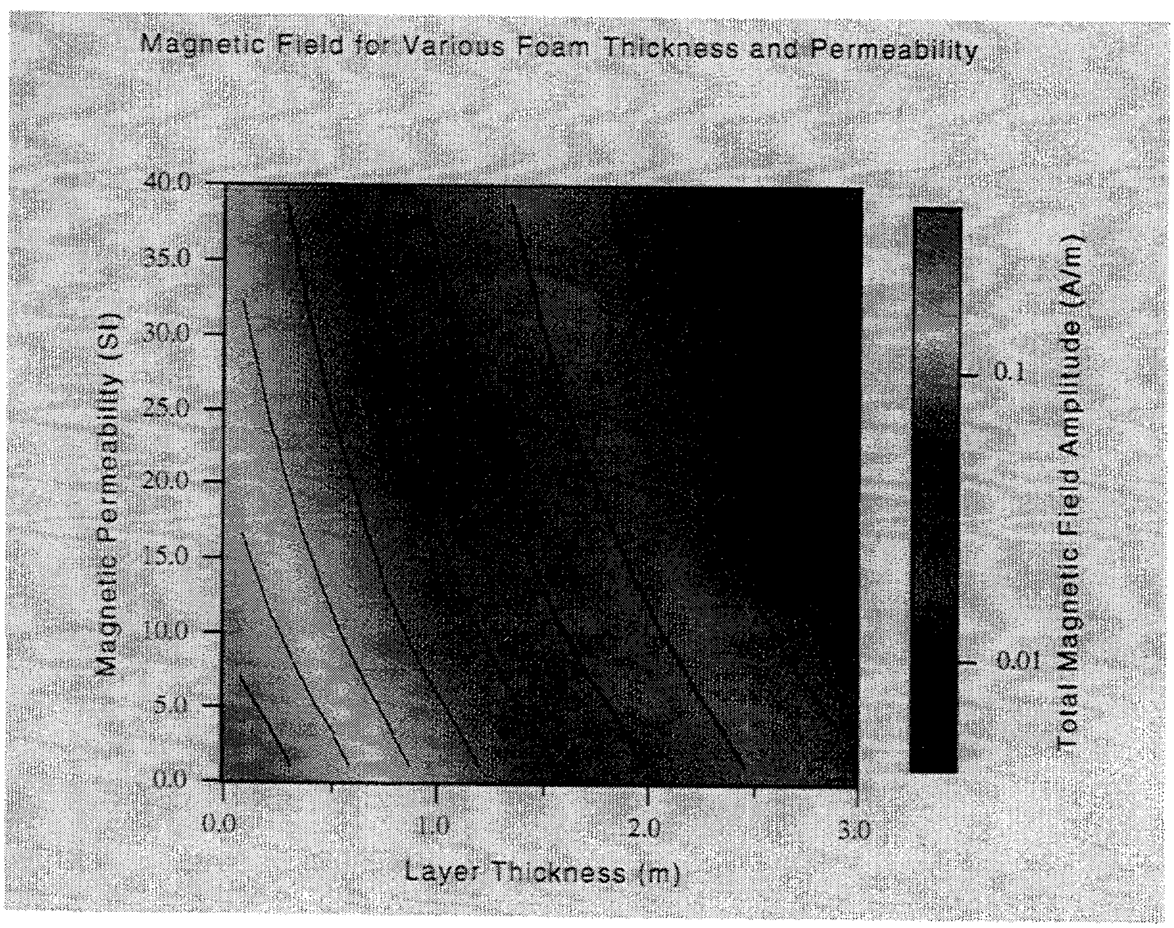


Figure E-2

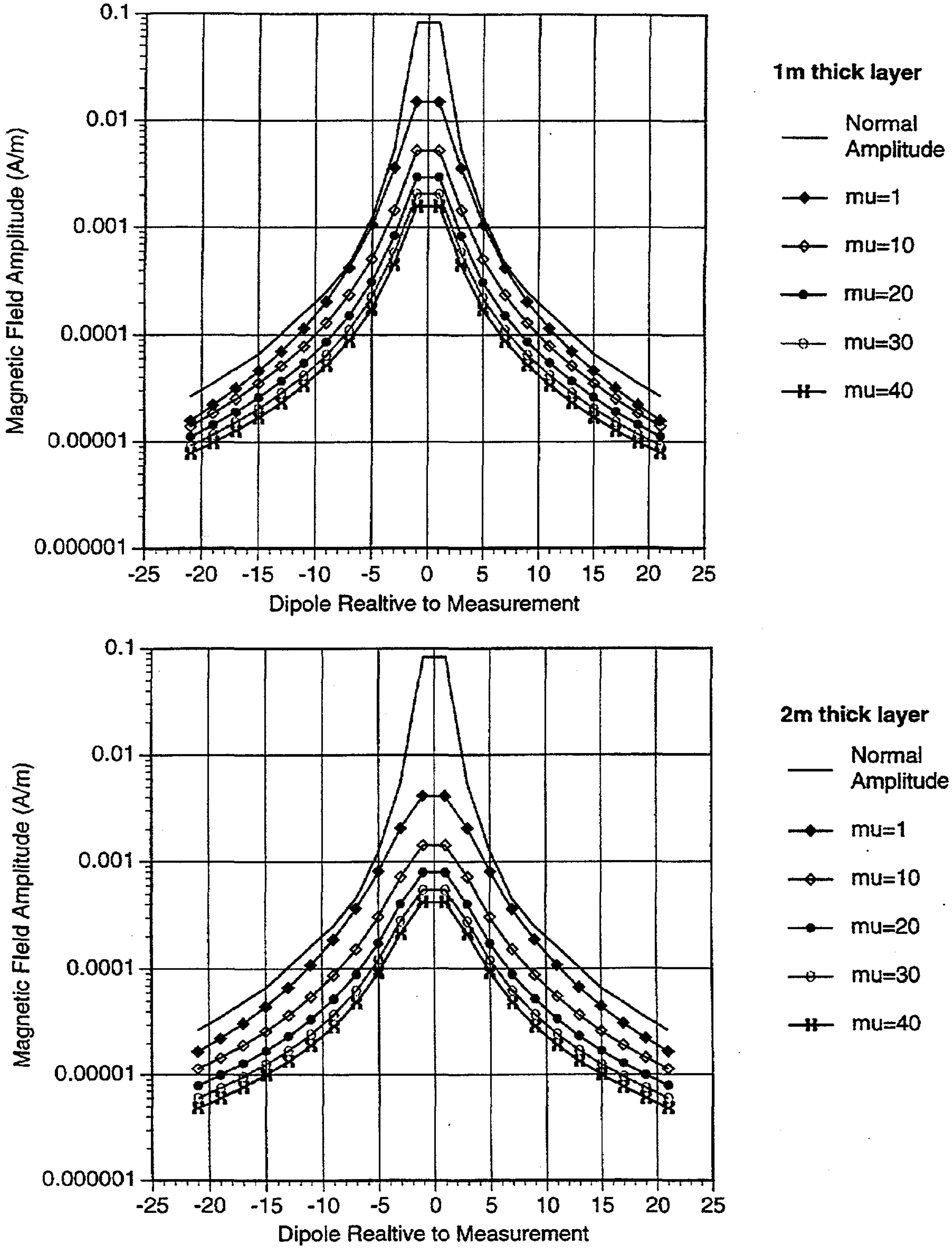


Figure 3

Figure E-3

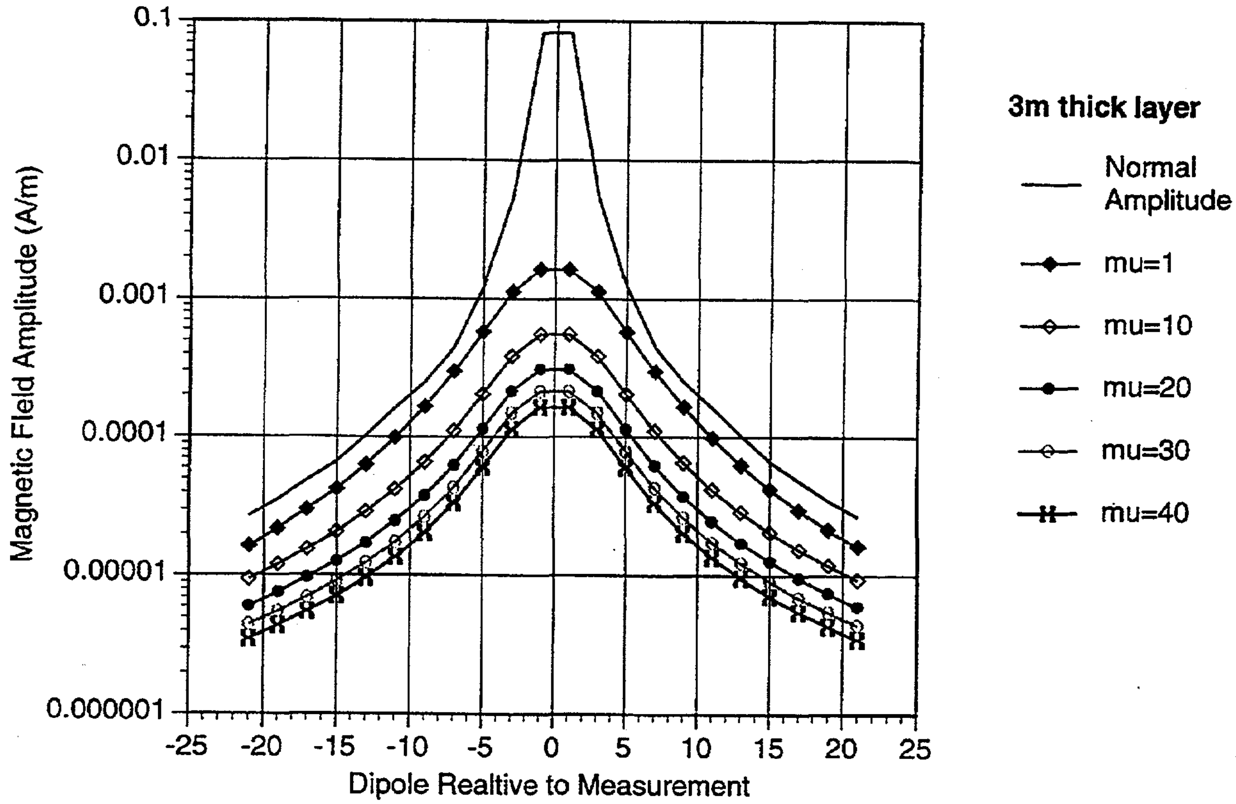
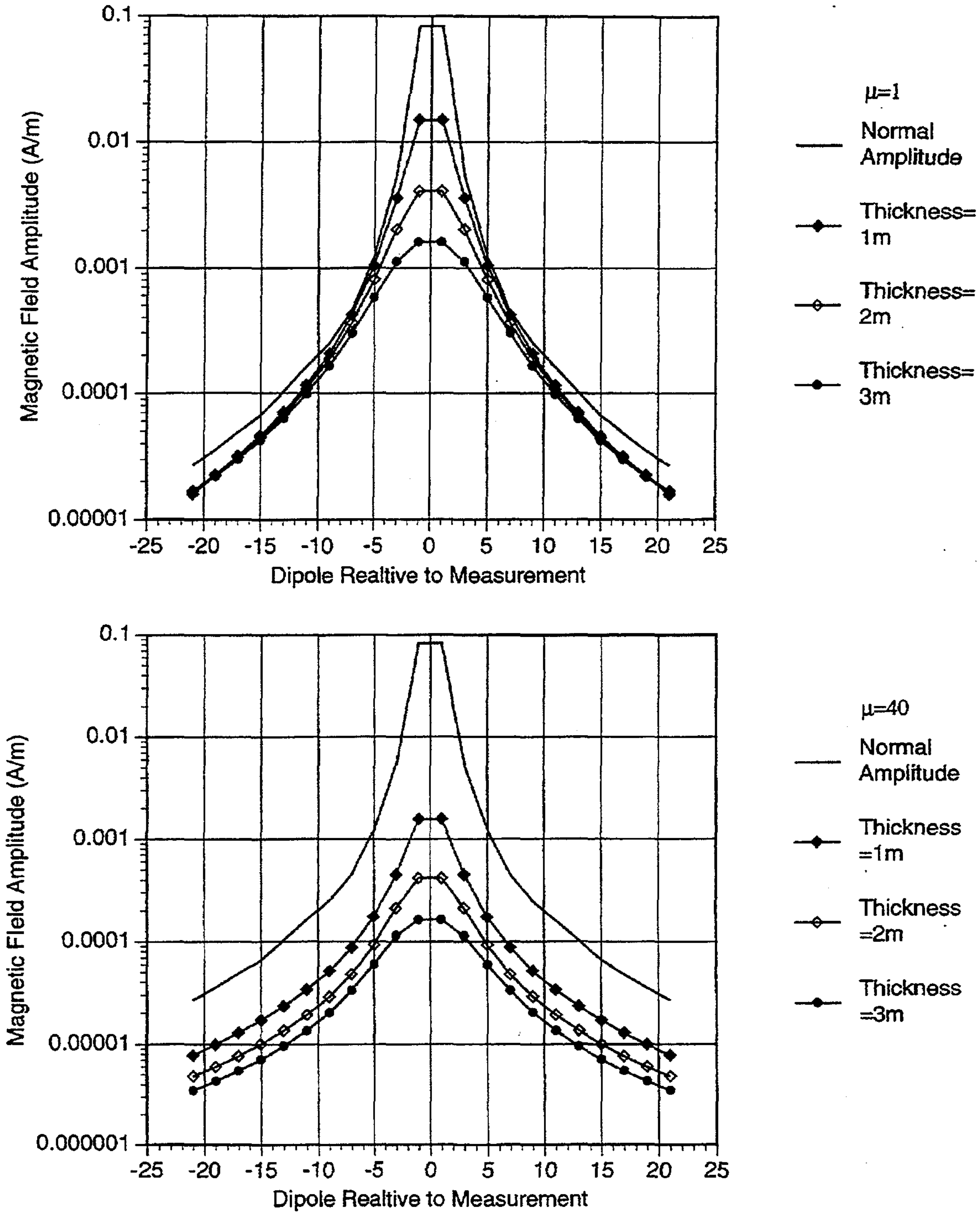


Figure E-3 (concluded)



Magnetic Field Amplitude (A/m)
0.1
0.01
0.001
0.0001
0.00001
-25 -20 -15 -10 -5 0 5 10 15 20 25
Dipole Realtive to Measurement
μ=1
Normal Amplitude
Thickness= 1m
Thickness= 2m
Thickness= 3m
Magnetic Field Amplitude (A/m)
0.1
0.01
0.001
0.0001
0.00001
0.000001
-25 -20 -15 -10 -5 0 5 10 15 20 25
Dipole Realtive to Measurement
μ=40
Normal Amplitude
Thickness =1m
Thickness =2m
Thickness =3m

Figure E-4

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