

BLAST AND FRAGMENTATION SUPPRESSION WITH AQUEOUS FOAM AND A KEVLAR TENT

Sponsored by the Directorate of Safety Health and the Environment, U.S. Army Garrison

*Presented at the Twenty-Eighth Department of Defense Explosive Safety Seminar
Orlando, Florida
18 – 20 August 1998*

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Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE AUG 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Blast and Fragmentation Suppression with Aqueous Foam and a Kevlar Tent				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 21005				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001002. Proceedings of the Twenty-Eighth DoD Explosives Safety Seminar Held in Orlando, FL on 18-20 August 1998.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 19	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

ABSTRACT

Aqueous foam has long been considered a good material to suppress the blast from an explosive event. The airblast produced is reduced significantly if the explosive is covered with an aqueous foam. However, for fragmenting munitions, the foam does not reduce the velocity of the fragments significantly. In order to reduce the hazard more effectively, the fragments must be stopped or reduced, along with the blast suppression.

The U.S. Army Research Laboratory (ARL), under sponsorship of U.S. Army Garrison Directorate of Safety, Health, and the Environment (DSHE) and with the cooperation of the Chemical-Biological Defense Command (CBDCOM), Aberdeen Proving Ground (APG) are currently investigating a field system to suppress the blast overpressure and stop the fragments from chemical munitions that cannot be moved or relocated for disposal and must be blown in place. The system consists of a commercial device developed jointly by CBDCOM and Zumro Inc. It consists of an inner and an outer kevlar tent. The explosive device of interest is prepared for detonation, and the outer tent is placed over it. The outer tent is approximately 13 ft x 10 ft x 8 ft tall and it does not have a floor. The inner tent is approximately 7 ft in diameter at the base tapering, to 4 ft at the top, and is 3 ft tall. It is placed inside the outer tent directly over the explosive device. The inner tent is then filled with Silvex foam formulation

The role of the outer tent is to stop any fragments that may have penetrated the inner tent and to contain any chemical or biological agent that may have been released by the explosive device. In the fielded situation under investigation by DSHE, the outer tent system is connected to a portable air scrubber/carbon filter. All escaping gas going out of the primary tent into the secondary tent is captured and run through the scrubber/carbon filter system. The scrubber/carbon system is being independently investigated by DSHE and CBDCOM. This paper covers the ballistic testing that is currently being performed to evaluate the ability of the system to suppress the blast overpressure and contain the fragments.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support and continued encouragement from Mr. Ed Newell (Project Manager (PM) for Lauderick Creek and the Prototype Detonation Test and Destruction Facility [PDTDF]), U.S. Army Garrison Directorate of Safety Health and the Environment (DSHE), Aberdeen Proving Ground (APG), and all of the members of the PDTDF Committee.

INTRODUCTION

One of Aberdeen Proving Grounds Environmental Study Areas is the Lauderick Creek Study Area. The area was used as a chemical training area from 1920 until 1951. Smoke and tear gas were the most common used ordnance in the training; however, some agent-filled munitions, phosgene (choking agent) and mustard (blistering agent), were also used.¹

¹ APG Web Page http://www.apg.army.mil/garrison/safety-environ/restor/lauderick_creek.html

The standard Army-approved method for disposing of agent-filled munitions that cannot be moved is open detonation. To ensure incineration of all the agent present, the weight of the explosive used is five times the weight of the agent. Hence, for a munition with 28.8 lbs. of agent 144 lbs. of explosive is required. In remote areas, this is not a problem, however, the Lauderick Creek Study Area is situated immediately adjacent to a populated area. Bordering the Lauderick Creek Study Area is an Amtrak railway, local communities, schools, daycare centers, etc. The 5:1 technique is not the preferred method to use at Lauderick Creek on munitions due to the tremendous blast overpressure that would be imposed on the local communities.

As an alternative to the 5:1 technique, a double-kevlar tent and foam system developed by the Chemical/Biological Counterterrorism Team of the Chemical-Biological Defense Command (CBDCOM) at the Edgewood Research, Development and Engineering Center (ERDEC) and Zumro Inc is being investigated. Zumro Inc in Willow Grove, PA. manufactures it. The system consists of an inner kevlar tent, also referred to as the Chemical Biological Explosives Containment System (CBECS) and an outer kevlar tent referred to as the workshelter.

The CBECS is a kevlar tent approximately 7 ft in diameter at the base. It tapers to approximately 4 ft at the top, with a height of approximately 3 ft. The floor is attached to the tent and has a 2-ft-diameter hole in the center, and the top has a sock to fill the tent with foam. There are no doors in the tent. The only openings are the hole in the floor and the filling sock. The tent is supported by a pneumatic structure that can be inflated with either a CO₂ cartridge or an air pump. It has flaps on the outside so it can be held down with sandbags, loose dirt, or other similar material. The purpose of the CBECS is to suppress the blast overpressure from a munition and stop or slow down any fragments.

In order to contain a chemical agent, the CBECS is placed inside a workshelter. The CBECS is then filled with foam. The workshelter is another kevlar tent approximately 13 ft wide, 10 ft long, and 8 ft high and is also supported by a pneumatic structure. The workshelter does not have a floor; however, it has flaps on the inside and the outside so it too can be stabilized with sandbags, loose dirt, or other similar material. It has a door with a zipper to allow people to come in and out of it. The workshelter is intended to contain the residual effects that escape from the CBECS. Vent socks are attached to the workshelter to facilitate the addition of a vacuum pump and/or filtration system to keep the tent under negative pressure and filter the agent. An illustration of the CBECS and workshelter is shown in figure 1.

Since the agent is being filtered and not incinerated the 5:1 ratio of explosive weight to agent weight would not be required using this system. The only explosive needed would be that used to open the round. A small shaped charge on the order of a quarter pound or less is being investigated.

The CBECS and workshelter are research and development (R&D) prototypes and patents are pending.

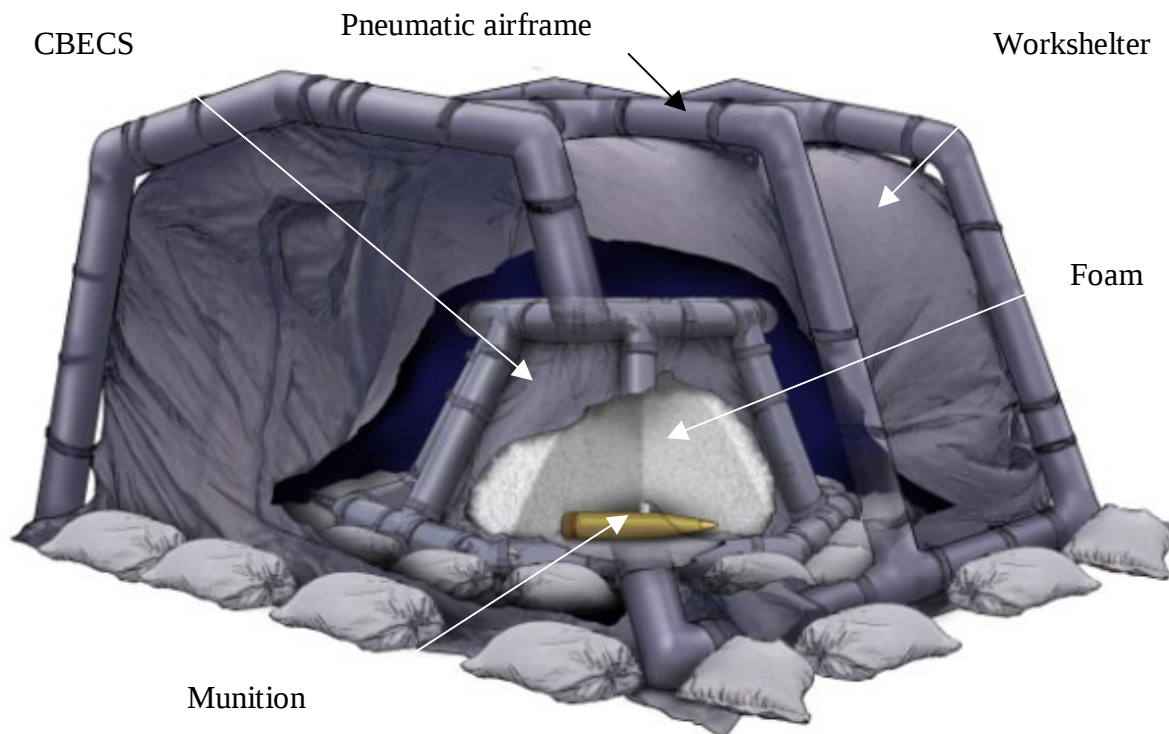


Figure 1 Components of the tent system

EXPERIMENTAL PROGRAM

The CBECS is designed to suppress the blast of the munition or device reacting. To accomplish this, the CBECS is placed over the device and then filled with Silvēx foam. Use of the foam within the CBECS is critical. It is not intended to be used without foam. For any experiments discussed in this paper where the CBECS was used, it can be assumed that it was filled with foam. No experiments were performed with the CBECS and no foam. Unpublished tests have been done on the CBECS to determine if it could withstand the effects of a small terrorist bomb in a toolbox.²³ The toolbox test was successful. However, the full capabilities of the CBECS have not been completely investigated. It is desirable to know the limits of the CBECS's capabilities with respect to chemical munitions, especially those such as livens projector, 4.2-in Stokes mortar, etc., which would be encountered at Lauderick Creek; so, an experimental program was designed to increase the explosive weight within the CBECS until it ruptured.

The experimental program was designed to answer two questions. The first was what amount of blast overpressure would rupture the CBECS. The second question was how much overpressure the CBECS suppressed. To answer these questions, the experiments were limited to blast overpressure without the introduction of fragments. For this reason, the first phase of the experimental program consisted of detonating various charge weights of bare explosives. Cylindrical charges of Composition B (40% TNT, 60% RDX) were

² Seitzinger, Al. Private communications. Chemical-Biological Defense Command (CBDCOM)

³ Laughton, Nelson. Private communications. Technical and Management Services Corporation (TAMSCO)

used in weights of $\frac{1}{4}$ lb. (113.5 g), $\frac{1}{2}$ lb. (227.0 g), and $\frac{3}{4}$ lb. (340.5 g). The L/D (length/diameter) of all the charges was 1.

Experiments were performed with and without the CBECS to access its ability to suppress blast overpressure. The baseline experiments were done with only the bare charges on open ground, the CBECS was not present. Blast overpressure measurements were taken at 5 ft, 13 ft, and 25 ft from the charge. Pressure measurements were taken with PCB 137A blast pressure probes and recorded on a Nicolet Pro 60 oscilloscope with a sampling rate of 5 us per point.

Experiments were then performed with the foam-filled CBECS with the various bare charges to determine how effective it was in suppressing the blast overpressure. To do these experiments, the charge was placed on the ground and wired for detonation. The CBECS was then positioned over the charge and filled with Silvēx foam. For these experiments, only the CBECS was used, the workshelter was not positioned over the CBECS. An illustration of the experimental setup is shown in figure 2.



Figure 2 Bare charge within the CBECS

Material failure of the CBECS is not necessarily considered a failure of the system. The blast overpressure can still be suppressed by the foam within the CBECS prior to tearing of the kevlar. If this occurs, the workshelter is capable of containing the agent, which then goes to a filtration system without a release to the environment.

RESULTS

Baseline Experiments

Baseline experiments were performed for each of the three charge weights to determine pressures without the CBECS in place. Figures 3, 4, and 5 are the pressure plots from the 25-ft gage for the $\frac{1}{4}$ -lb., $\frac{1}{2}$ -lb. And $\frac{3}{4}$ -lb. charges respectively. On each figure, three pressure traces from repetitive experiments are plotted. It can be seen from these figures that the pressure curves and instrumentation used to obtain them are very repeatable.

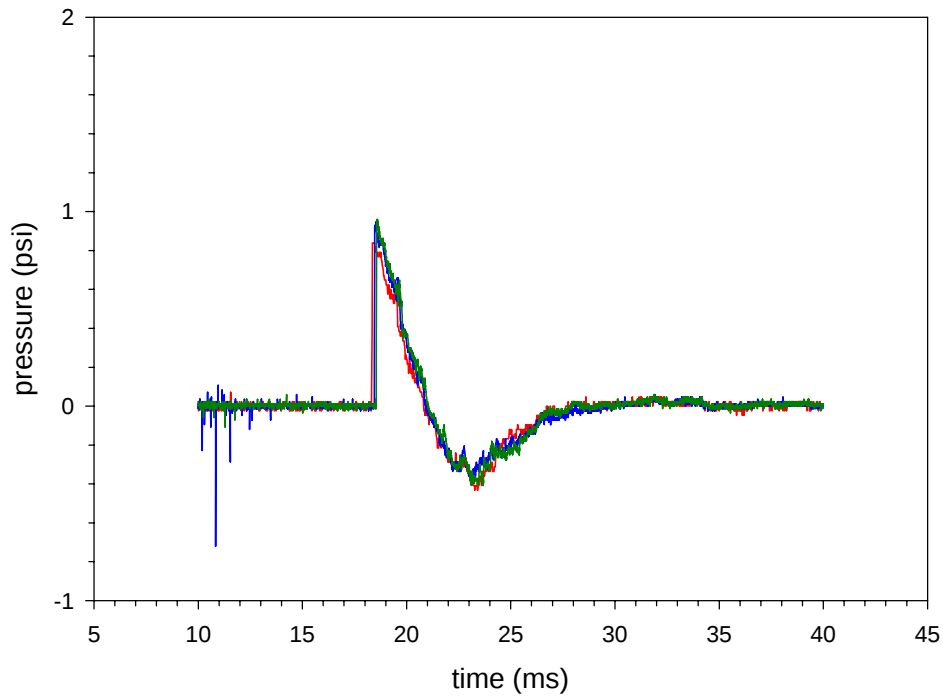


Figure 3 Pressure traces from the 25-ft gage during the $\frac{1}{4}$ -lb. experiments. Baseline - no CBECS

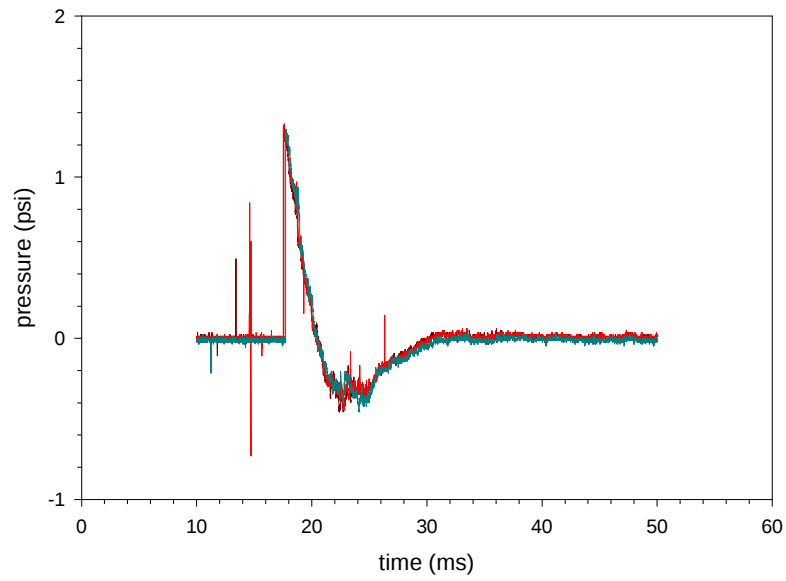


Figure 4 Pressure traces from the 25-ft gage during the 1/2-lb. experiment. Baseline – no CBECS

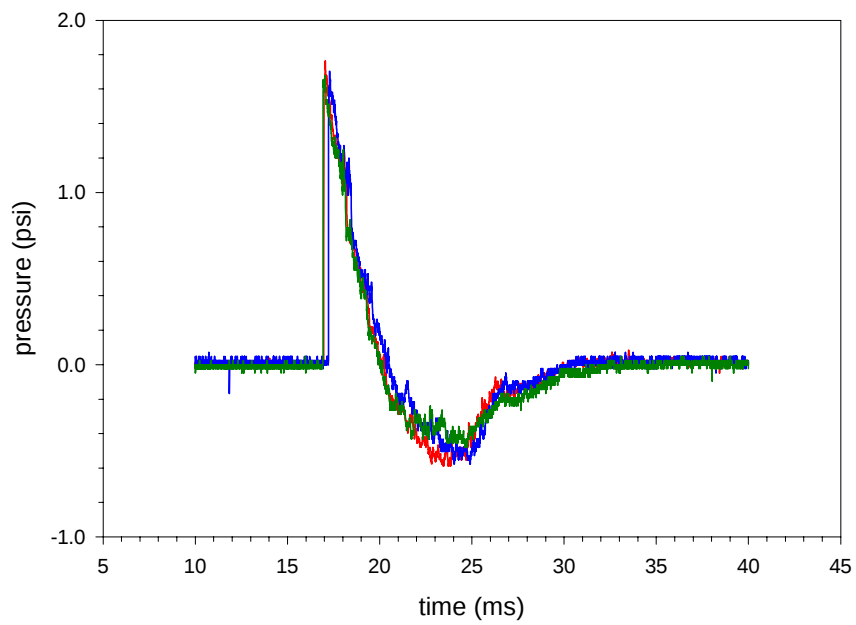


Figure 5 Pressure traces from the 25-ft gage during the 3/4-lb. experiments. Baseline - no CBECS

Physical Damage to the CBECS

A total of eight experiments was performed with the CBECS and the Silvex foam; two ¼-lb., four ½-lb., and two ¾-lb. experiments. For all of the ¼-lb. experiments the CBECS survived the event with minimal damage. The only damage during these experiments was some tearing on the floor of the CBECS at the opening where the charge was positioned. However, both of the ¾-lb. experiments caused the CBECS to rupture at the seams. The same CBECS was used for the two ¼-lb. experiments and the first ¾-lb. experiment. All of the remaining experiments used new CBECS's. Photographs of the tear in the seams of the CBECS can be seen in figures 6, 7, and 8.



Figure 6 Damage to the CBECS after the ¾-lb. experiment

The first two experiments with the ½-lb. charges were similar to the results of the ¼-lb. experiments, there was only minimal damage to the CBECS floor at the opening for the charge. However, the third test caused the CBECS to tear at the seams similar to the tearing that occurred in the experiments with the ¾-lb. charge. At the time it was not clear why the CBECS tore so a fourth experiment was performed to see if it was possibly a faulty CBECS or some other circumstance unique to this particular experiment.



Figure 7 Damage to the vertical seam after the $\frac{3}{4}$ -lb. experiment

The fourth experiment was similar to the first two; there was no tearing of the CBECS. The only damage was around the hole in the floor where the charge was placed.

There is an explanation of the tearing of the CBECS during the third $\frac{1}{2}$ -lb. experiment. When this experiment was performed, there was a misfire, and the charge did not detonate. The reason for the misfire was a loose wire in a junction box outside of the bomb proof. This was discovered and fixed relatively quickly and the charge was detonated. However, approximately 10 to 15 minutes passed between the time of the misfire and the actual detonation of the charge. During this time, the foam within the CBECS was settling. It is possible, although not conclusive, that within this 10-to-15-minute window, the foam settled enough to make it less effective in its ability to suppress the blast, similar to not filling the CBECS completely with foam. This settling effect of the

foam is observed after each of the experiments. When an experiment is completed, the CBECS is picked up and the remaining foam is left on the ground and eventually dissipates. (In an actual chemical event, some of the



Figure 8 Damage to the horizontal seam during the $\frac{3}{4}$ -lb. experiment

agent might remain in the foam, [mustard for example] on a cold day). This would require some clean up, including the soil. However, aerosolization of the agent to the local community would be prevented.

It is also possible that there was a defect in the material or the manufacturing process, and this is being independently investigated.

It is the authors' belief that the CBECS can withstand up to ½ lb. of bare explosive without damage under normal circumstances. If the charge weight is increased to ¾ lb. or the foam sits for an extended period of time, it is likely there will be physical damage to the CBECS. However, physical damage to the CBECS does not necessarily mean a failure of the system.

The charge weights tested were aimed at determining the amount of explosive that would rupture the CBECS. The chemical munitions that are likely to be encountered at Lauderick Creek only contain a small amount of explosives. The livens for example has approximately 0.19 lbs (88 grams) of explosive. Even with a small shaped charge (less than a ¼ lb.), the total explosive weight in an actual event in the field will be smaller than that required to tear the CBECS.

Pressure Measurements

The peak pressures from the experiments with and without the CBECS are shown in table 1. The pressure reductions are quite significant with the CBECS in place. For example, the ½-lb. charge baseline experiments

	<i>5-ft Gage</i>		<i>13-ft Gage</i>		<i>25-ft Gage</i>	
	Bare charge	CBECS and foam	Bare Charge	CBECS and foam	Bare Charge	CBECS and foam
¼-lb. Charge	10	No data	2.5	0.10	0.8	0.07
	14	0.20	2.8	0.10	0.9	0.04
	10		2.5		0.9	
½-lb. Charge	19	0.29	3.7	0.10	1.3	0.04
	22	0.27	4.1	No data	1.3	0.08
	23	0.4*	4.0	0.29*	1.3	0.16*
		0.29		0.12		0.06
¾-lb. Charge	30	0.44	4.6	0.17	1.8	0.11
	30	0.34	4.8	No data	1.7	0.09

	30		4.9		1.7	
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* The CBECS tore during this ½-lb. experiment. The 5-ft gage peaked, actual pressure at the 5-ft position was greater than 0.4 psi.

Table 1 Peak pressures (all pressure data in psi)

gave peak pressure measurements between 19 and 23 psi at the 5-ft foot gage location. When the CBECS was in place that pressure was reduced to 0.29 psi. Figure 9 is a plot of the pressure records from the 5-ft gage for the ½-lb. experiments. One pressure trace is the baseline experiment, and the other is the experiment with the CBECS. Plotted on the same scale as it is in figure 9, the pressure trace for the experiment with the CBECS appears to be a flat line. Figure 10 is the pressure traces of the two ½-lb. experiments with the CBECS. From these traces it can be seen that there is indeed some minimal pressure measured.

The pressure gages used, PCB 137A23, have an operating range of 0–50 psi with a resolution of 0.005 psi. The CBECS and foam reduced some of the blast pressures to the point where some of the pressure records were

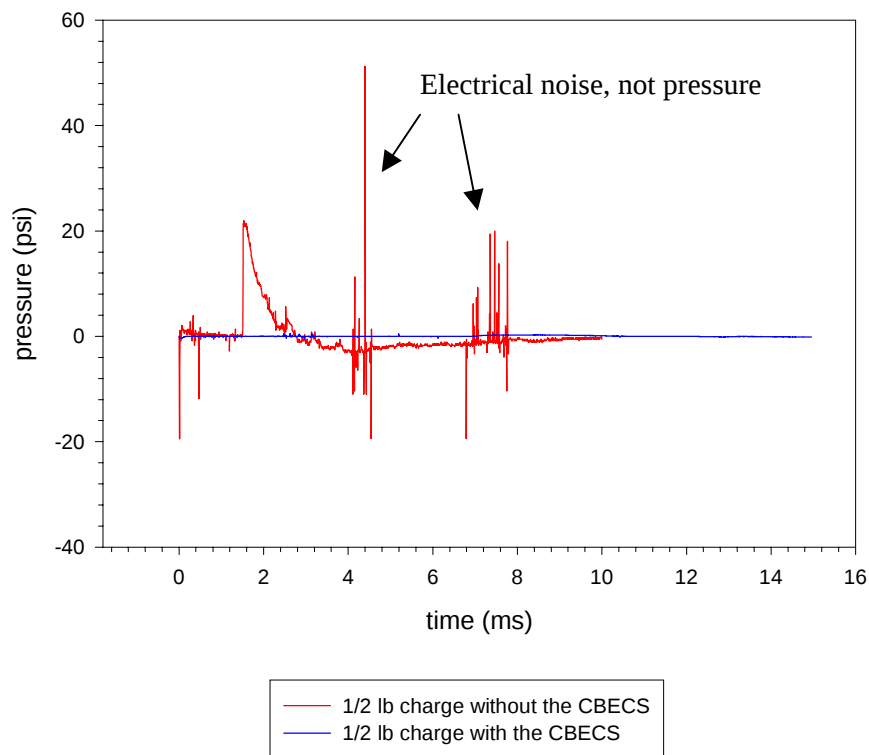


Figure 9 Pressure records at 5-ft from two ½-lb. experiments, one with and one without the CBECS

close to the noise range of the gage. The ¼-lb. and ½-lb. charges measured at the 25-ft gage location are an example. Those pressures range from 0.04 to 0.08 psi. Even though the pressure records are very low and there

is a lot of noise there is a distinct pressure wave. Figure 11 is a plot of the ¼-lb. charge with the CBECS and foam in place. Both of the experiments are on the pressure plot.

It should also be noted that even though there was tearing at the seams in the experiments with the ¾-lb. charges the pressure measurements were still reduced significantly. The pressure readings at the 5-ft gage position were 30 psi for the baseline ¾-lb. experiments. When the CBECS and foam were added, the pressure readings were reduced to 0.44 and 0.34 psi for the two experiments. The same reduction occurred for the other gages, the 25-ft gage went from a 1.8-psi baseline pressure to a 0.11-psi pressure with the CBECS and foam. Even though part of the CBECS tore at the seams, the experiments were still considered a success. In field the objective of the CBECS is to reduce the pressure from the blast wave and to stop or slow down any fragments that are present. The CBECS accomplished its task of reducing the blast pressure. There were no fragments used during these experiments. Experiments with actual rounds and fragments are scheduled at a later date.

For a comparison basis, the pressure traces for the ¼-lb., ½-lb., and ¾-lb. experiments are shown in figures 12-14. It can be seen from the various pressure traces that the CBECS decreases the pressure significantly for all three of the charge weights, even though there was some tearing of the CBECS on the larger charge.

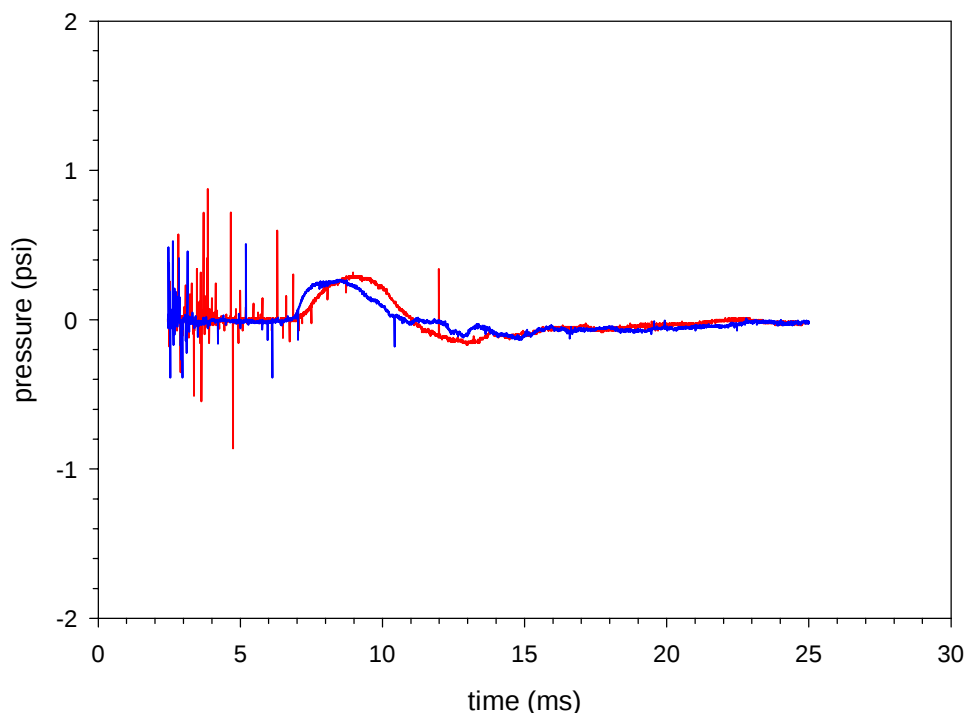


Figure 10 Pressure records at 5-ft from two of the ½-lb. experiments with the CBECS

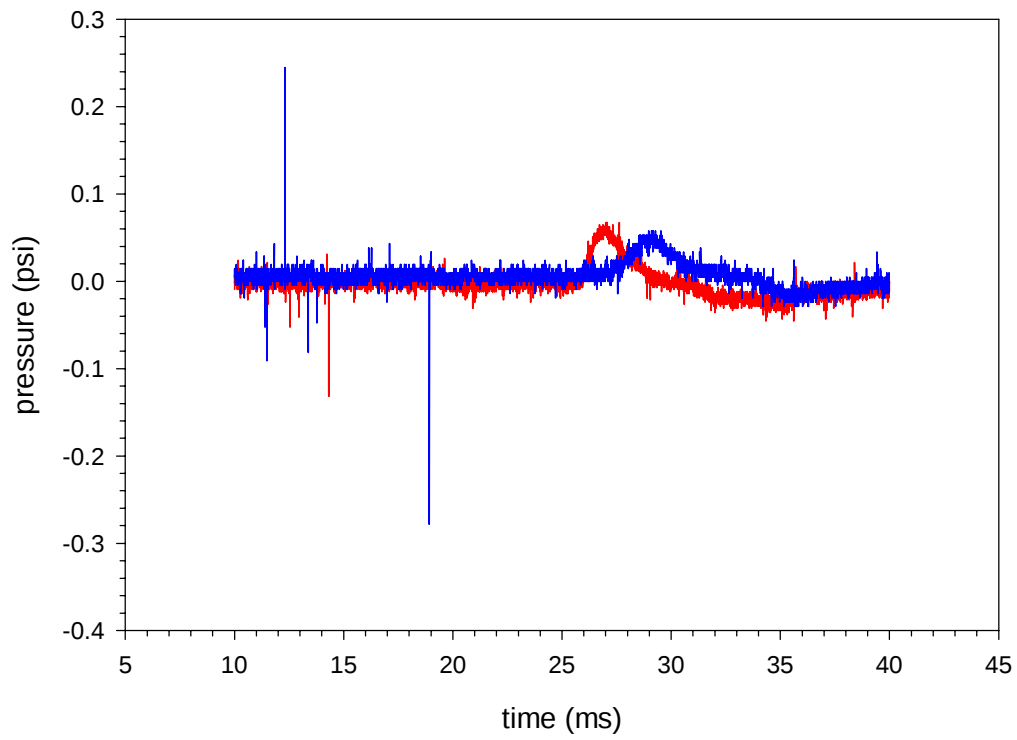


Figure 11 Pressure records from the two ¼-lb. experiments with the CBECS (25-ft gage)

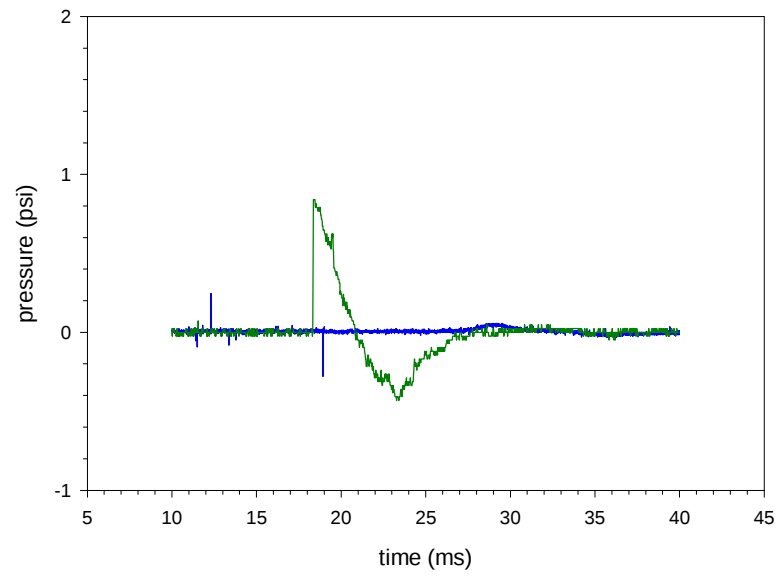


Figure 12 1/4-lb. pressure traces with and without the CBECS (25' gage)

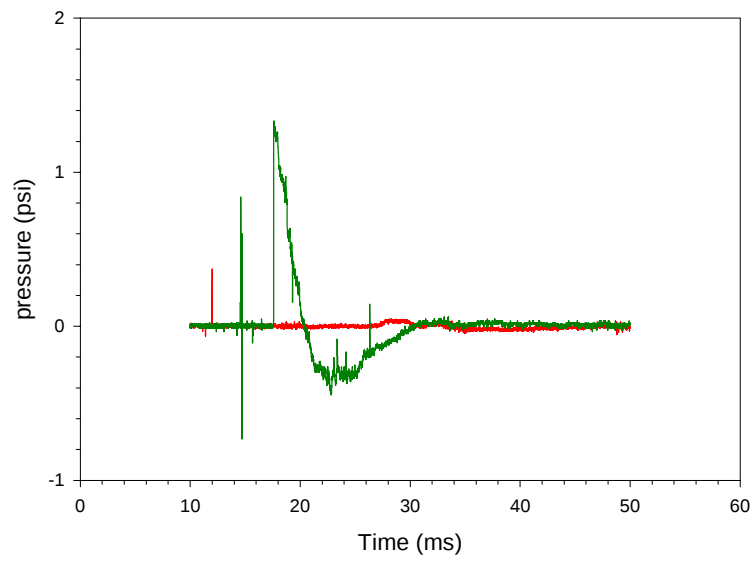


Figure 13 1/2-lb. pressure traces with and without the CBECS (25-ft gage)

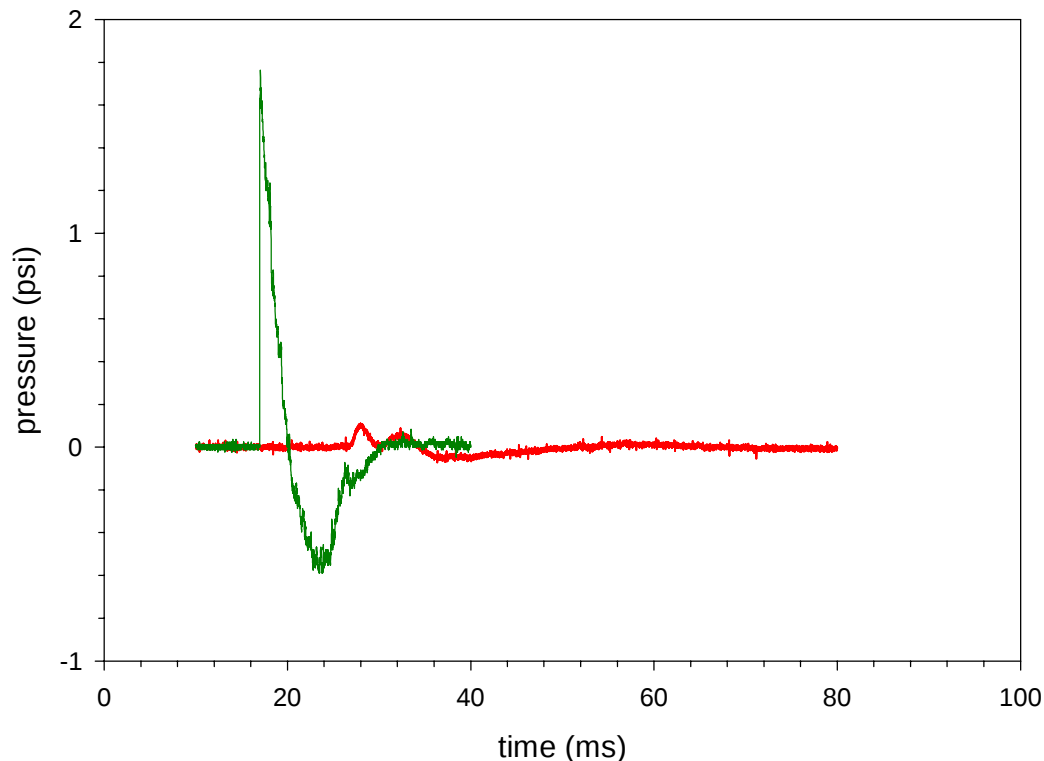


Figure 14 $\frac{3}{4}$ -lb. pressure traces with and without the CBECS (25-ft gage)

Acoustics of Blast Waves

The Human Resources Engineering Directorate (HRED) of the U.S. Army Research Laboratory computer code Auditory Hazard Assessment Algorithm – Human (AHAAH 1.0) is used to calculate the effects of a blast wave on the human ear. This model takes a blast pressure waveform of an event as its input and generates the sound pressure level (SPL) and a table of resulting Auditory Damage Units (ADU) as a function of frequency and location along the cochlear membrane in the inner ear. The Society of Automotive Engineers (SAE) has given tentative approval for this model as a standard for airbag noise.

Table 2 is a representative listing of some of the experiments performed. In the table the experiments are grouped in sets of two, identical in all ways except for the presence or absence of the CBECS. In all cases, the CBECS suppressed the sound pressure levels (SPL) by significant amounts. A difference of 3 dB represents a factor of 2 in energy. More significant are the changes in ADUs in comparison of the baseline and CBECS experiments. ADUs of less than 200 are not considered harmful, and less than 400 should be recoverable. Beyond 400 ADUs, permanent damage to the inner ear is likely to occur.⁴

⁴ Price, Richard, Private Communications. Human Resources and Engineering Directorate, U.S. Army Research Laboratory, Aberdeen Proving Ground

<u>Charge Wt. (lbs.)</u>	<u>Range (ft)</u>	<u>CBECS present</u>	<u>dB_{MAX}</u>	<u>ADU_{MAX}</u>
1/4	5	NO	193.7	1562.0
1/4	5	YES	156.6	2.1
1/4	13	NO	179.7	292.5
1/4	13	YES	151.0	11.5
1/4	13	NO	178.7	395.1
1/4	13	YES	150.8	10.7
1/4	25	NO	168.8	151.0
1/4	25	YES	147.3	7.3
1/2	25	NO	173.0	92.7
1/2	25	YES	143.4	8.1
3/4	13	NO	184.6	178.9
3/4	13	YES	155.4	12.4
3/4	25	NO	175.9	174.8
3/4	25	YES	151.6	17.0

Table 2 Decibel (dB) and Auditory Damage Units (ADU) of selected experiments

CONCLUSION

The CBECS was successful in suppressing the blast pressure wave from bare explosive charges. With a ¼-lb. charge, there was not any damage to the CBECS, other than some tearing on the floor at the location where the charge was placed. This minimal damage was expected and is acceptable. When the charge weight was increased to a ½ lb. the CBECS survived three out of four experiments with minimal damage. For one of the tests however there was some significant tearing on the vertical seams of the CBECS. However, it is the authors' belief that this is due to the fact that there was an abnormally long weight period between the time the foam was placed in CBECS and the time the charge was initiated. During this time, it is likely that the foam settled and the CBECS was no longer completely filled with foam. For the ¾-lb. experiments there was tearing of the CBECS for both.

The chemical munitions likely to be encountered at Lauderick Creek contain only a small amount of explosives, on the order of 0.19 lbs (88 g). If a small shaped charge is used to open the rounds, then the total amount of explosive can be kept small enough to prevent tearing of the CBECS.

Although the CBECS tore in the ¾-lb. experiments, the pressure waves measured by the blast gages were still reduced significantly. It would be difficult, if not impossible, to look at the pressure records of the ¾-lb. experiments and determine from those alone that there was tearing in the CBECS.

The CBECS is intended to be used in conjunction with the workshelter. Even for the ¾-lb. experiments where the CBECS tore when the workshelter is in place there would be very little pressure that would affect the workshelter.

The CBECS also reduced the SPL and the associated ADUs significantly.

FUTURE WORK

The ability of the CBECS and the workshelter to stop fragments from chemical munitions is being investigated. Special Equipment Test Hardware (SETH) rounds are new rounds built to the specifications of the original 4.2-in chemical munitions except they do not have any chemical or explosive components. Some SETH rounds have been obtained and are being modified slightly. The burster tube will be filled with Composition B explosive and the chemical portion will be filled with water. These rounds will be initiated with a ¼-lb. shaped charge, and flash x-rays will be used to characterize the fragments.

Once the fragments are characterized this information will be compared with published data on kevlar and its ability to stop fragments to determine what effect the fragments will have on the CBECS. When this is completed, proof tests will be conducted with the SETH rounds inside the CBECS.

The final results of this work will be published in an ARL technical report.