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Two Tests for Explosive Countermine Studies

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TWO TESTS FOR EXPLOSIVE COUNTERMINE STUDIES

by

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ABSTRACT

This study investigated measurement techniques for use in two proposed tests applicable to explosive countermine studies. Carbon resistors were used as pressure gauges in an adaptation of the Naval Weapons Center Small-Aquarium Test to determine the shock-to-detonation threshold for the Belvoir Research, Development, and Engineering Center mine analog. Thin-foil manganin gauges were used to demonstrate the capability of measuring the shock output of explosives, as applicable to distributed explosives countermine systems.

INTRODUCTION

Although potentially a major factor on the modern battlefield, countermine warfare has seen little progress since World War II. Common countermine systems destroy a mine by actuating the mine's fuze mechanism. The current work in explosive countermine systems has grown out of earlier work with fuel-air-explosive (FAE) systems. These systems detonate mines by pushing the mine pressure plates with a shock from the FAE. These are ineffective against modern mines that employ a variety of sensors in the fuze. One approach with potential to overcome the advances in fuze technology is direct attack of the mine main charge with explosive shock. Systems have been developed that have optimized FAE shock output. However, the stoichiometry of FAE limits potential shock output to levels insufficient for direct defeat of a mine main charge.

Our work provides the tools necessary to establish boundaries for future explosive countermine studies. It answers the basic complementary questions of what level of shock strength is required to initiate main-charge detonation? and what level of shock strength does a countermine system deliver? This work produced a possible standard test to determine the shock vulnerability of various mines, established data for the Belvoir Research, Development, and Engineering Center (BRDEC) mine analog, and developed techniques to measure the shock output of explosive countermine systems.

MINE DETONATION THRESHOLD

Origin of Test

Our preliminary considerations included work done by the Naval Weapons Center (NWC), China Lake, California, in which they used a Pentolite (50% PETN, 50% TNT) donor charge in water to shock an acceptor charge to determine the shock sensitivity of damaged explosives and propellants.[1] The reported small-aquarium test seemed easily adapted to our needs and had been successfully modeled at Los Alamos National Laboratory.[2] The underwater aspect of the test also raised the possibility of noise abatement. Noise/shock minimization was a concern for BRDEC because they intend to conduct tests at Fort Belvoir in the future. Even though a large amount of water would be required, it remains a possibility.

Our initial attempts to establish a source of Pentolite were not successful. Several Navy sources reported Pentolite on hand, but that Pentolite was no longer commercially available. We judged that the ready availability of the donor explosive was an important consideration for a test intended to be a standard. Because it is both readily available and very energetic, we designed our early tests to calibrate PBX 9501 for use in the test. Previous work at Los Alamos with calibrated, standard charges in water provided the opportunity to contribute to our knowledge of carbon resistor pressure gauges while adapting the test to use PBX 9501. However, before full-scale testing with

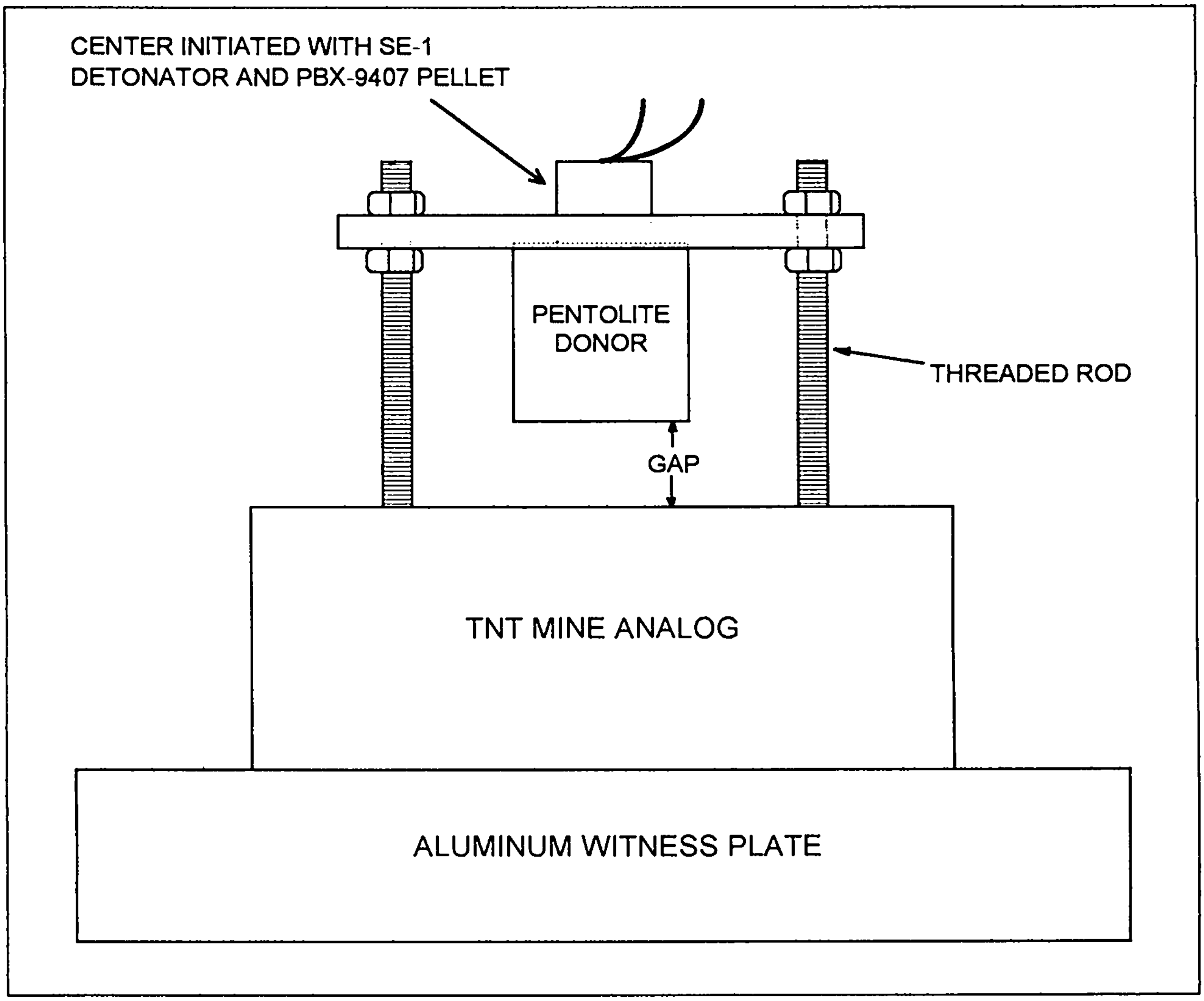


Fig. 1. Schematic of experimental setup.

PBX 9501, we became aware of at least two commercial sources of Pentolite. With the long-term availability of Pentolite relatively secure, and considering the obvious cost advantages of using the same charge specified in the NWC work, we decided to drop our plans to calibrate PBX 9501 and ordered a supply of Pentolite.

The use of water as a transmission medium provides a well-understood universal coupler to the acceptor mine. We will continue to refer to this test as an aquarium test.

Experimental Setup

The test equipment that went into the aquarium is shown in Fig. 1. The target was the BRDEC mine analog. The analog is an 8- by 6- by 3-in. box fabricated of 20-gauge steel. One end of the analog has two filler plugs for casting into the container either Composition B or TNT explosive. We used TNT in this study because it was less sensitive than Comp B. The fill and case thickness are a good representation of many of the actual mines of interest to the Army. The U.S. Army Ballistic Research Laboratory (BRL) cast our supply of mine analogs. Owing to reported difficulties in casting and reported differences between the response of the U.S. M-15 antitank mine and the BRDEC mine analog, we decided to radiograph the analogs received. We were looking for any internal inconsistencies in the cast TNT, such as voids caused by shrinkage. The radiographs and density profiles of analogs 13B and 9B are shown in Figs. 2 and 3, respectively. These were the two analogs tested with a 15-mm gap.

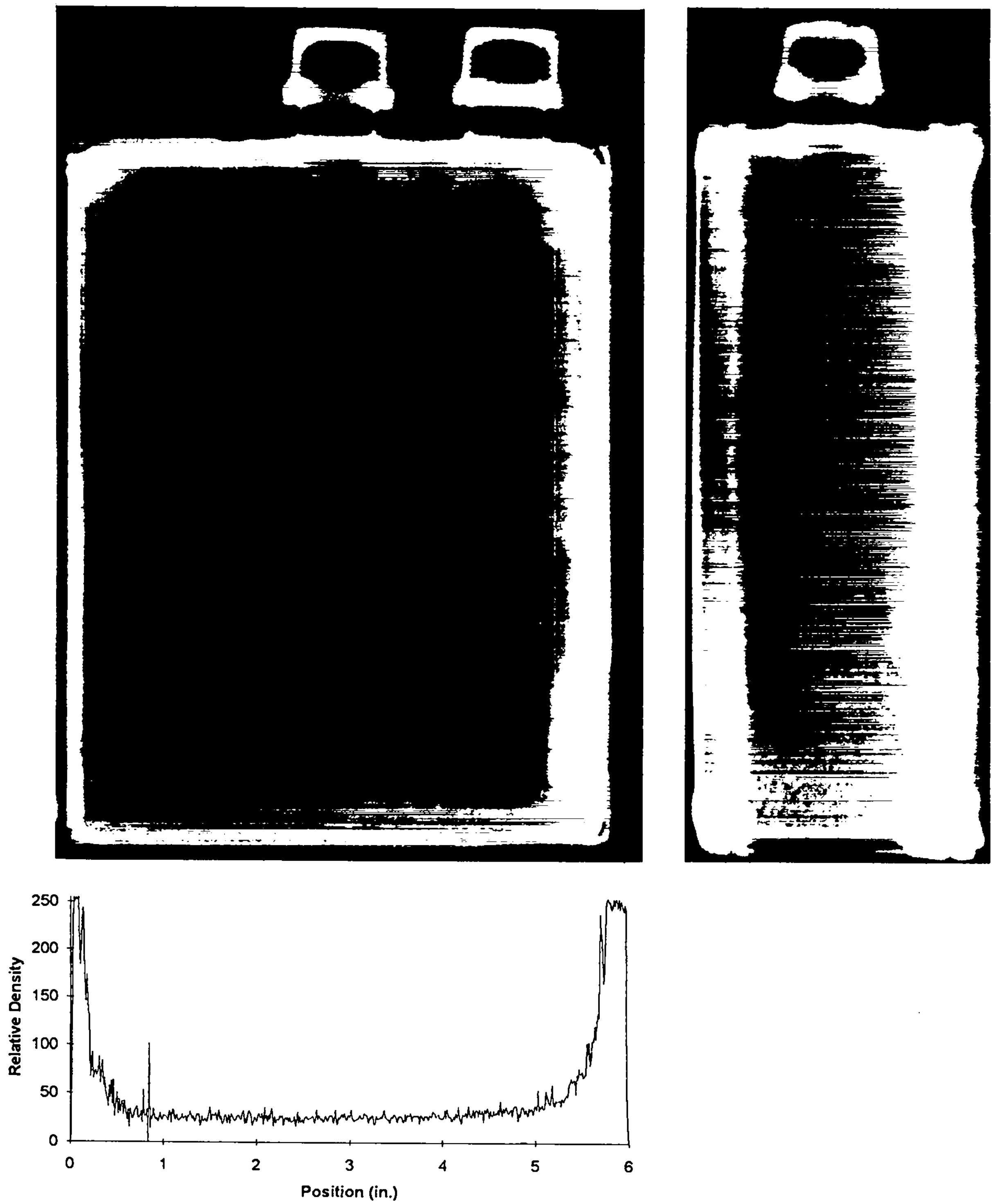


Fig. 2. Radiograph and midpoint density profile of mine analog 9B.

We used three forms of donor explosive in our experiments. Two shots used precision spheres of PBX 9205. The Pantex facility pressed and machined the spheres, 3 in. and 5 in. in diameter, respectively. These spheres were center-initiated with bidirectional, slapper detonators custom fabricated at Los Alamos by M-7, the Detonation Systems Group.

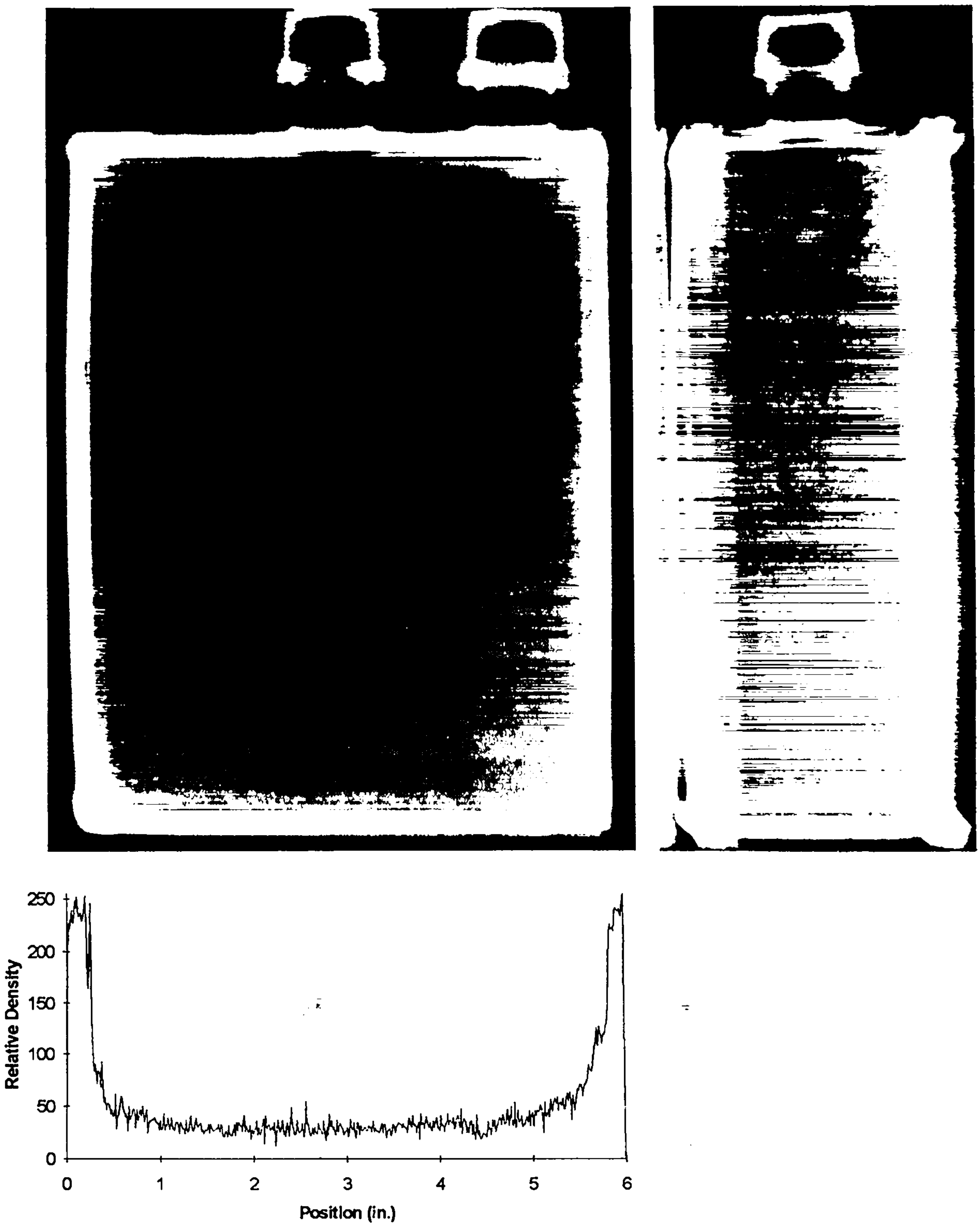


Fig. 3. Radiograph and midpoint density profile of mine analog 13B.

The spherical output of these donors had previously been established.[3] We intended to have one analog detonate and one not detonate. These donors were expected to provide a known input for our carbon resistor gauge arrangement, to bound the shock-to-detonation-transition (SDT) threshold of the analog, and to provide initial data necessary for the conversion of the small aquarium test to PBX 9501. For the reasons presented previously, we discontinued our efforts to convert the test to PBX 9501. In all subsequent tests we used the Pentolite donor standardized for the NWC small-aquarium test. This Pentolite donor consists of two Pentolite cylinders each 2 in. in diameter and 1 in. long, pressed to a density of 1.56 g/cm^3. We had hard-plastic tubes, 2 in. in diameter, machined to precise lengths for placement between the Pentolite and the mine analog. These tubes aided the precise fixing of the analog-to-donor gap. The positioning aid was removed before each shot was fired.

Instrumentation

Shock Timing Pins

We used common 150-V, stand-off shock pins to detect shock arrival and transit times for some of the shots. The pins trigger a time interval meter started with the firing pulse.

Witness Plate

In the experimental arrangement described above, we used an instrumented witness plate under the mine analog, as shown in Fig. 1. The plate assembly consisted of a 2-in.-thick piece of 6061-T6 aluminum alloy approximately 10 in. by 12 in. Two small grooves were cut into the top face of the plate to accommodate the leads for the carbon resistor gauges. The gauges were positioned about 1 in. apart, near the center of the plate. A 1/16-in.-thick aluminum cover plate was glued to the top of the plate to avoid free-surface effects arising from irregularities in the analog surface in the pressure measurements.

Carbon Resistor Pressure Gauges

Watson[4] showed that commercial carbon resistors display an apparently reproducible change in resistance when subject to either static or dynamic pressures. Building on our own work[5] and the work of others, we have modified commercial 1/8-W resistors so that they have acceptable survivability in dynamically loaded environments. We used standard 1/8-W, nominally 470-Ω resistors made by the Allen-Bradley Co. to measure the dynamic pressure on the exit side of the mine analogs that had been explosively loaded. Waves with amplitudes up to 150 kbar and risetimes in the microsecond range are within the capability of these devices. Calibration, construction, and related electronic systems and other issues regarding carbon resistor gauges are discussed in detail in Ref: 5.

Results

The results of the shots with the PBX-9205 precision spheres will not be discussed in this report. Because the digital recording device failed on one of the shots, the data obtained from the single remaining shot are too limited to draw meaningful conclusions.

The shots using Pentolite were fired in two series. The aluminum witness plates from the first five shots are shown in Fig. 4. A summary of the results follows and is shown in Table I.

40 mm 20 mm 15 mm 10 mm 5 mm

Fig. 4. Aluminum witness plates.

TABLE I. AQUARIUM TEST DATA

Shot No.	Analog ID Number	Gap (mm)	Calculated Shock into Analog (kbar)	Measured Peak Exit Pressure* (kbar)	Shock Transit Time (μs)	Postshot Witness Plate Thickness (in.)
B-9716	9	5	133.5	---------	---------	1.210
C-6428	11B	10	105.9	Failed before peak	21.0	1.130
B-9718	13B	15	83.9	217.8	---------	1.190
C-6430	9B	15	83.9	28.8	25.8	1.900
C-6429	10B	17.5	74.7	22.4	29.3	1.925
B-9717	8	20	66.5	33.1	---------	1.780
B-9715	4	40	26.6	5.1	---------	1.995
C-6431	8B	5	133.5	Failed before peak	17.7	steel

*in witness plate

A photo comparing the witness plates from the two shots with 15-mm gaps is shown in Fig. 5. The pressure data are shown in Figs. 6 and 7.

Series 1

Shot No. B-9715: 40-mm gap, nearly imperceptible bow in the witness plate

Shot No. B-9716: 5-mm gap, witness plate shattered into several pieces

Shot No. B-9717: 20-mm gap, gentle bow in the witness plate

Shot No. B-9718: 15-mm gap, heavy bow in the witness plate with a distinct imprint of the analog

Series 2

Shot No. C-6428: 10-mm gap, witness plate heavily dented and cracked, edges broken off

Shot No. C-6429: 17.5-mm gap, witness plate slightly dented

Shot No. C-6430: 15-mm gap, witness plate slightly dented

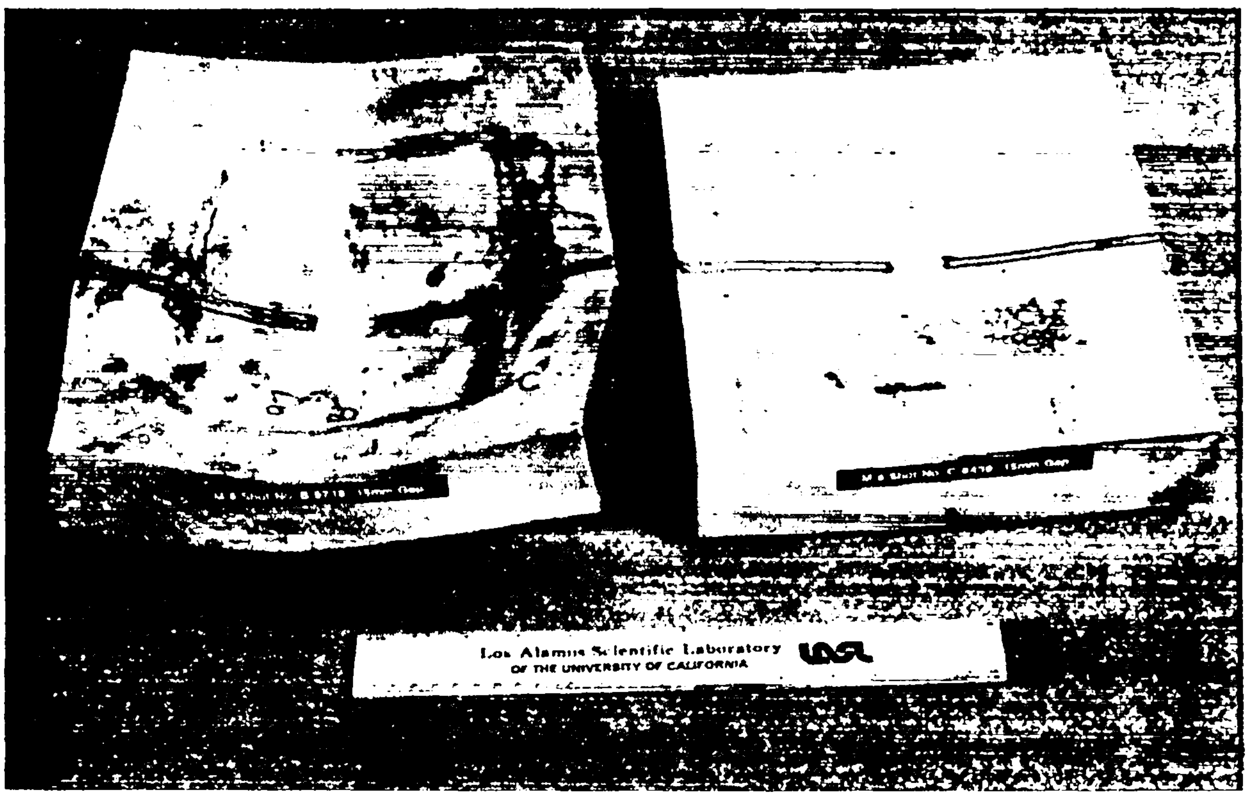


Fig. 5. Witness plates from identical tests with 15-mm gap.

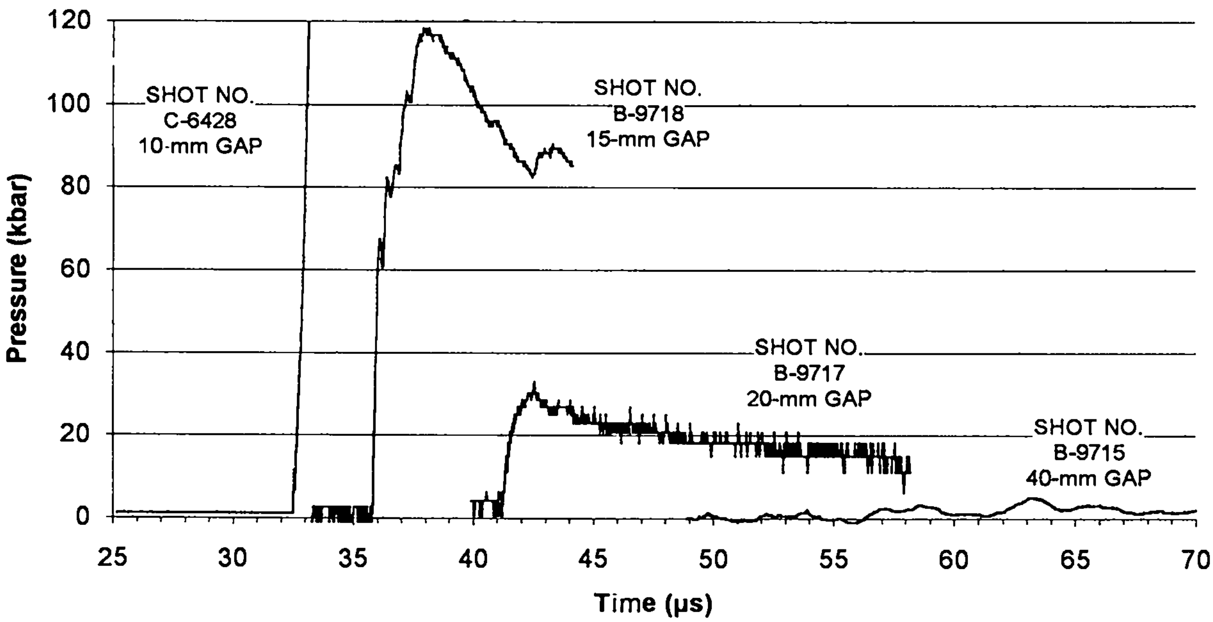


Fig. 6. Measured witness pressures.

Shot No. C-6431: 5-mm gap, heavy bow in steel witness plate with a distinct imprint of the analog and spall cracks on back side

Analysis

As in any gap test, the information sought is the point at which the test yields a detonation 50% of the time. The detonation threshold must be considered as a range of donor shocks, across which the probability of detonation rises from near zero to near one. Inconsistencies in the analog fill will serve to widen the range, but even perfect fill cannot completely narrow it. BRL certainly used more care when casting our mine analogs than would be expected from any production process, and therefore, the defects in the explosive fill of production mines would probably be more severe than we can see in the radiographs taken of our mine analogs. The radiographs of the tested analogs still show fill defects that could affect their shock sensitivity, but the relative consistency of our data does not support an evident correlation between fill defects and analog detonation. The skill and experience of BRL personnel in casting explosives are clearly evident in the consistent performance of the mine analogs.

The aluminum witness plate has proven itself to be a useful tool in judging the degree of reaction initiated in the analog. Figure 4 shows the wide range of plate responses observed in the testing. We were able to discern small differences in energy release initiated in the TNT fill because of the amplitude of effects seen in the aluminum plates, as opposed to those in steel. The test fired with a gap of 5 mm and a steel witness plate caused only as much deformation as the 20-mm test shown in Fig. 4. The aluminum is a much more sensitive gauge of reaction violence.

The pressures measured with the carbon resistor gauges under the mine analogs mirror the effects observed in the witness plates. The more severe the plate effects, the higher the pressure we measured. Certainly this is not surprising, but it is further evidence of the proper performance of the pressure gauges. The data in Figs. 6 and 7 are displayed without smoothing or other data filtering. This shows the user the form of the data taken initially by the digital recorder.

Because of the similarity of the test to common plate-dent tests and the observation that the witness plates were undergoing substantial plastic deformation, we decided to measure the postshot plate thickness at the thinnest point, near the approximate center of the plate. The results are listed in Table I and shown in Fig. 8. This graph has some interesting features. Most obvious is the step function exhibited in the plate thickness measurements. This seems to indicate that, as reaction violence increases, little plate thinning occurs until a

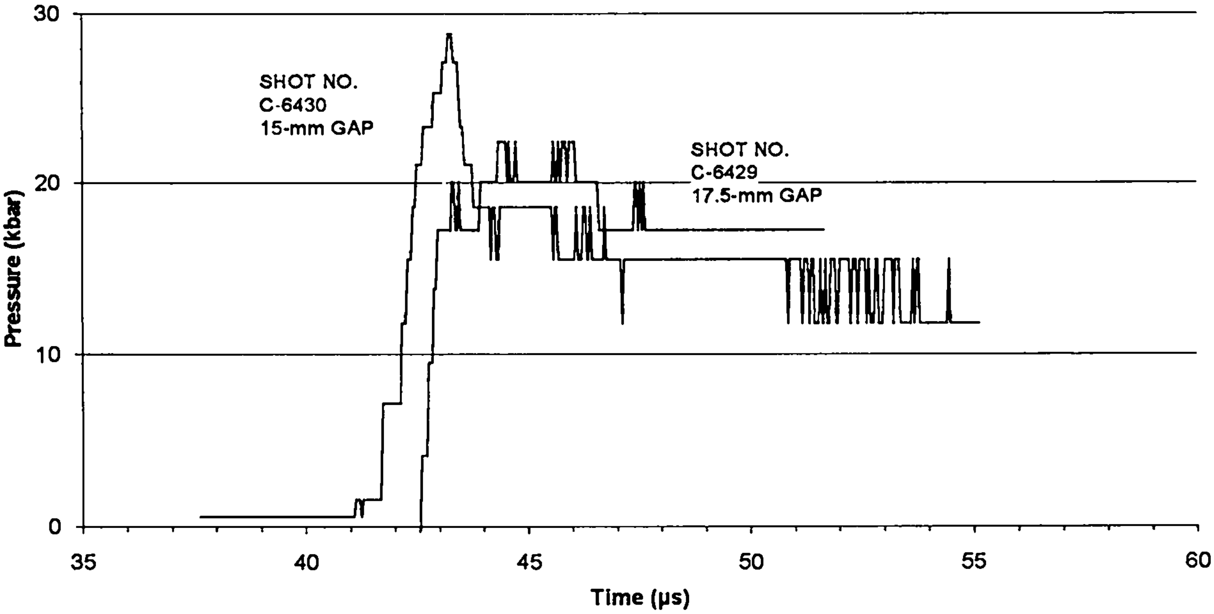


Fig. 7. Measured witness pressures

threshold is reached. Further increases in reaction violence do not appear to cause additional thinning, but rather they contribute to the onset of plate breakup. The presence of significant plate thinning could be used as an obvious threshold to define detonation for the test. Again, note that the peak witness pressures correlate well with the plate thicknesses. Owing to gauge or recorder failure, we were unable to record peak pressures for the shots with less than a 15-mm gap. The sharp step at 15 mm would certainly be smeared by readings from more shots. The graph would likely show a band of gaps, across which the probability of detonation increases, and the middle is defined as the detonation threshold.

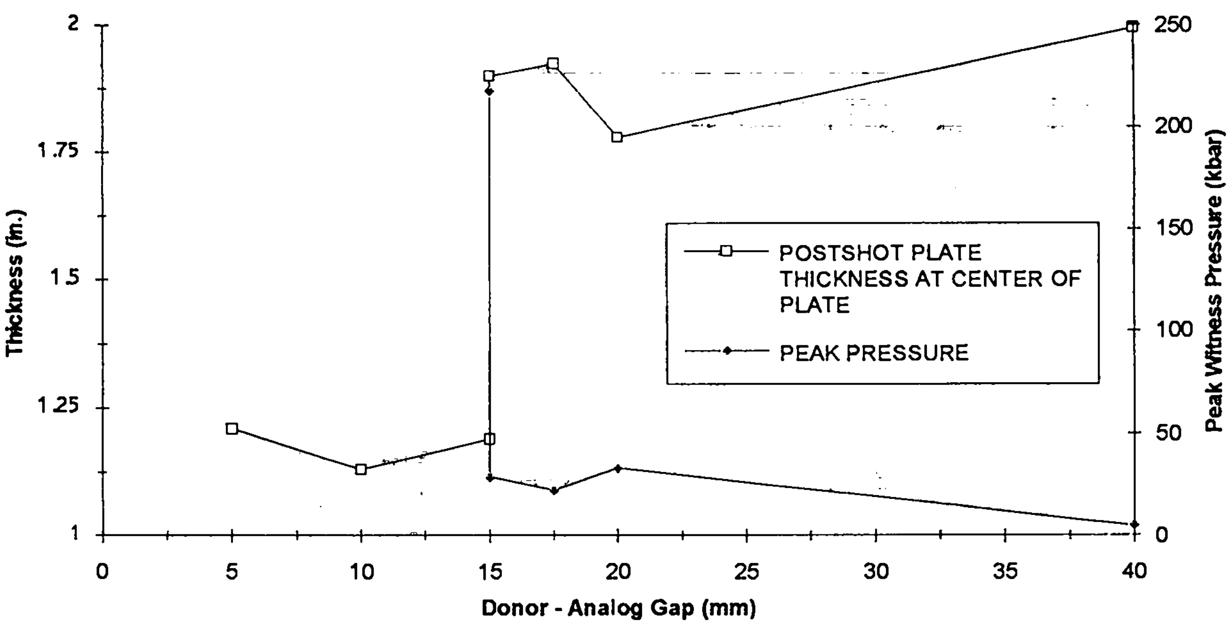
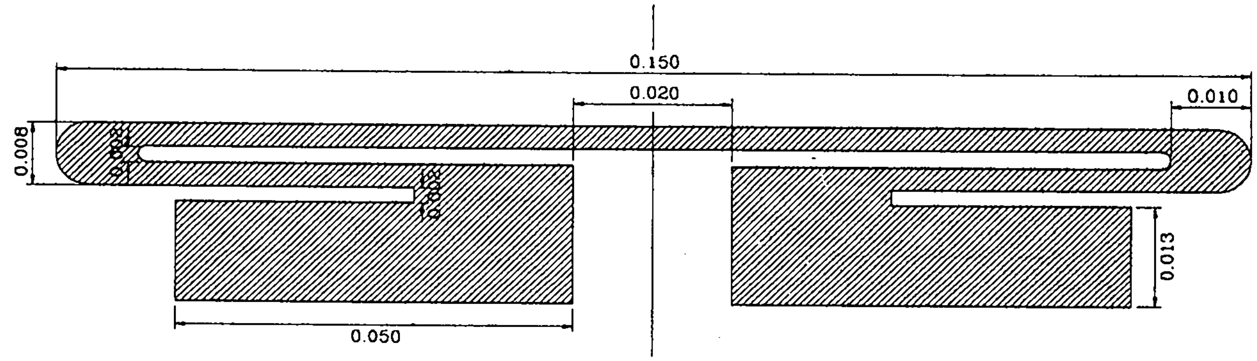


Fig. 8. Postshot witness plate thickness.



Note: Drawing not to scale.
All dimensions in inches.

Fig. 9. Sketch of manganin "T" gauge.

Our research confirms what many others involved in explosive countermine studies have already found. The main charge of a mine is a formidable target, if classic detonation is the single criterion for success. However, during the customary inspection of the firing mound after each explosive experiment, we found no explosive from any of the analogs in any of the shots. In fact, the only remnant of the analog we ever found was the bottom plate from the analog used in the 40-mm gap test.

Although classic detonation is a criterion that ensures success, perhaps it is unnecessarily ambitious. The troop commander definitely wants a smoking hole in the ground as clear evidence of mine destruction, but he does not care whether the smoke is the result of classic detonation or a vigorous deflagration. As long as the reaction is vigorous enough to destroy the mine and give visible evidence of that fact, the commander and the troops are satisfied. If this is true, rather than needing to know how hard we must hit a mine to cause detonation, it might be more useful to know how softly we can hit a mine and still produce the desired smoking hole in the ground.

Because lives are at stake, military systems are intentionally designed to include a degree of performance overkill. However, the constraints of the real world do not permit designs that are infinitely heavy, expensive, or complex. Overkill is expedient but undetermined until we know the required threshold. If we are willing to accept only reliable detonation as the criterion for success in minefield clearing, one of two situations will be the result. The successful system will be heavier and more expensive or cover less area than might otherwise be covered. Even worse is the potential situation where a proposed system is rejected because it cannot detonate mines; we might not realize that it will reliably clear a minefield by causing mine deflagration. Explosively clearing a minefield is an acknowledged difficult endeavor, but we ought not make it more difficult than it is.

OUTPUT MEASUREMENTS FOR COUNTERMINE SYSTEMS

Running-Wave Experiment

As part of the program to develop shock wave measurement techniques applicable to countermine studies, we had proposed to demonstrate a method for characterizing stress waves associated with running (sweeping) detonation waves. We ascertained that a gauge designed for this application was commercially available (Micro-Measurements, Model No. LM-SS-580SF-025). We obtained a supply of these gauges rather than fabricating gauges ourselves. This gauge was originally designed at Sandia National Laboratories.[6] Figure 9 is a schematic view of the gauge element. Its usefulness in the sweeping-pressure case arises from the very small dimension of the grid (0.20 mm) in the direction of the sweep of the wave. For example, a wave traveling at 6 mm/μs would traverse the active element of the gauge in 0.033 μs, which is about the same magnitude as the decrease in risetime response caused by the finite thickness of the insulated gauge package itself.

We performed three running-wave experiments using steel targets, sheet explosive (DuPont Detasheet™, C-3 and C-8), and the

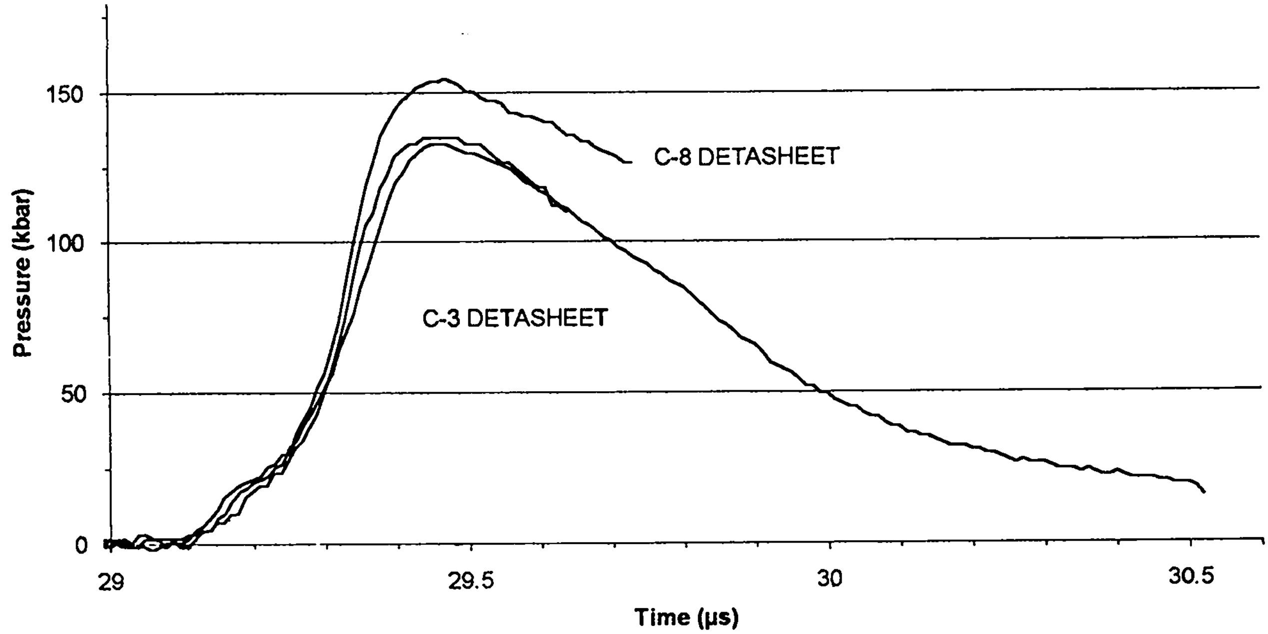


Fig. 10. Running-wave pressure data.

gauges described above. In each experiment, the target consisted of a 100- by 100-mm mild-steel base plate, grooved for the gauge, and a 1.6-mm-thick mild-steel cover plate, which was screwed to the base plate at the corners and also glued with epoxy. Extra Teflon™ sheet insulation (≈0.125 mm on each side) was placed on each side of the gauge. The sheet explosive was glued to the completed target assembly, and a line wave generator butted up against the appropriate edge of the explosive.

The results of the three experiments are summarized in Table II and Fig. 10. The two experiments done with the C-3 sheet explosive show good reproducibility. Data from the experiment done with the C-8 sheet explosive show a significantly higher peak pressure. This result is a thickness effect resulting from the more shallow Taylor wave associated with the thinner explosive. The wave generated by the thicker explosive is therefore attenuated less before the wave reaches the gauge. The results could also reflect some experimental scatter. More experiments are needed to establish the effect of explosive thickness on peak pressure. The 135-kbar pressure obtained with the C-3 sheet explosive agrees well with predictions.[7]

TABLE II. RUNNING-WAVE TEST PRESSURES

Shot No.	Test Explosive (Detasheet)	Peak Pressure (kbar)
B-9689	C-3	135
B-9690	C-3	137
B-9691	C-8	156

The structures in front of the main waves are elastic precursors with a magnitude of approximately 20 kbar, which could be expected in mild steel at these peak pressure levels. If we extrapolate the main wave from the peak down to the time axis, we see that the 10–90% risetimes are of the order of magnitude of 0.1 μs, which is normal for a gauge of this type.

A wave with a peak pressure of approximately 135 kbar in steel gives a peak pressure transmitted into TNT of <100 kbar, which is on the lower edge of the existing experimental distance-to-detonation data on TNT. TNT in a mine may not detonate under this type of attack, but the mine would definitely be destroyed.

FUTURE DIRECTIONS

Both sections of this study leave questions open to future study. Is main-charge detonation a reasonable and realistic goal for explosive countermine systems? How do the criteria for mine deflagration or destruction compare with transmitted-shock characteristics different for a sweeping detonation vs. a perpendicular detonation, as might be found in a bimodal countermine system? Are the same measurement techniques applicable to both types of waves?

ACKNOWLEDGMENTS

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We also wish to thank Stephen Sousk of BRDEC for his patience and assistance.

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