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Blast and Fire Propagation in Underground Facilities

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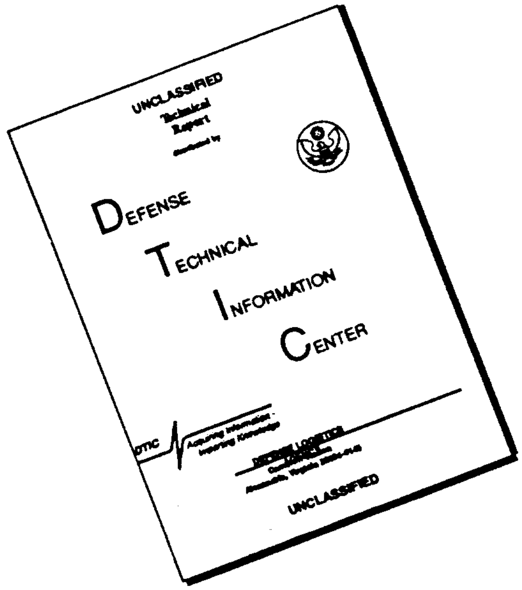

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13. ABSTRACT (*Maximum 200 words*)

This project investigates the behavior of blast waves from the detonation of explosives and premixed propylene oxide/air mixtures in an underground facility. Shots of C4, TNT, and propylene oxide predispersed in air were fired at the end of a 20-ft-wide by 6-ft-high tunnel and at the intersection of two tunnels. The effectiveness of detonation of predispersed propylene oxide/air mixtures was evaluated in two ways: through recording of the pressure of the blast wave and through the effect on targets (desks and computers). This report documents the experimental procedures employed and results obtained for three tests in this program; the detonation of a 28.8 lb sphere of C4 explosive and two shots involving the detonation of 20 lb of propylene oxide as premixed stoichiometric fuel/air mixtures. The three tests were selected in the belief that they would be most useful to researchers attempting to understand and model the effectiveness of explosives detonated in underground facilities. No attempt is made to explain or evaluate the results in this report.

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PREFACE

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CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ————————————▶ **BY** ————————————▶ **TO GET**
TO GET ◀———————————— **BY** ◀———————————— **DIVIDE**

angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter² (m²)
British thermal unit (thermochemi-	1.054 350 X E +3	joule (J)
cal)	4.184 000	joule (J)
calorie (thermochemical)	4.184 000 X E -2	mega joule/m² (MJ/m²)
cal (thermochemical/cm²)	3.700 000 X E +1	*giga becquerel (GBq)
curie	1.745 329 X E -2	radian (rad)
degree (angle)	$t_k = (t°f + 459.67)/1.8$	degree kelvin (K)
degree Fahrenheit	1.602 19 X E -19	joule (J)
electron volt	1.000 000 X E -7	joule (J)
erg	1.000 000 X E -7	watt (W)
erg/second	3.048 000 X E -1	meter (m)
foot	1.355 818	joule (J)
foot-pound-force	3.785 412 X E -3	meter³ (m³)
gallon (U.S. liquid)	2.540 000 X E -2	meter (m)
inch	1.000 000 X E +9	joule (J)
jerk		
joule/kilogram (J/kg) radiation	1.000 000	Gray (Gy)
dose	4.183	terajoules
absorbed	4.448 222 X E +3	newton (N)
kilotons	6.894 757 X E +3	kilo pascal (kPa)
kip (1000 lbf)	1.000 000 X E +2	newton-second/m² (N-
kip/inch² (ksi)	1.000 000 X E -6	s/m²)
ktap	2.540 000 X E -5	meter (m)
micron	1.609 344 X E +3	meter (m)
mil	2.834 952 X E -2	meter (m)
mile (international)	4.448 222	kilogram (kg)
ounce	1.129 848 X E -1	newton (N)
pound-force (lbs avoirdupois)	1.751 268 X E +2	newton-meter (N m)
pound-force inch	4.788 026 X E -2	newton/meter (N/m)
pound-force/inch	6.894 757	kilo pascal (kPa)
pound-force/foot²	4.535 924 X E -1	kilo pascal (kPa)
pound-force/inch² (psi)	4.214 011 X E -2	kilogram (kg)
pound-mass (lbm avoirdupois)	1.601 846 X E +1	kilogram-meter² (kg m²)
pound-mass-foot² (moment of iner-	1.000 000 X E -2	kilogram/meter³ (kg/m³)
tia)	2.579 760 X E -4	**Gray (Gy)
pound-mass/foot³	1.000 000 X E -8	coulomb/kilogram (C/kg)
rad (radiation dose absorbed)	1.459 390 X E +1	second (s)
roentgen	1.333 22 X E -1	kilogram (kg)
shake		kilo pascal (kPa)
slug		
torr (mm Hg, 0° C)		

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (GY) is the SI unit of absorbed radiation.

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SECTION 1

INTRODUCTION

1.1 GENERAL.

This report describes a program of research conducted by the Bureau of Mines under the DNA-funded project "Blast and Fire Propagation in Underground Facilities (UGF's), IACRO #93-862. The purpose of the research was to evaluate the performance of a propylene oxide/air detonation in the underground entries at the Bureau's Lake Lynn Laboratory and compare this to high explosives of comparable payload weights. Past experience has shown that conventional high explosives are relatively ineffective in destroying large hardened underground facilities. Fuel/air explosives (FAE's) can potentially release several times as much energy per pound of payload as high explosives when properly dispersed and initiated. The effectiveness of any explosive and particularly a fuel-air explosive in the destruction of a UGF is greatly affected by geometry. The room and pillar layout of the underground facilities at Lake Lynn Laboratory and the blast resistant design of the facility offers a unique opportunity to evaluate the effectiveness of a FAE in a realistic simulation.

1.2 LAKE LYNN LABORATORY.

The Bureau's Lake Lynn Laboratory is a unique mining research laboratory designed to provide a modern, full-scale mining environment for the testing and evaluation of mine health and safety technology. Although the facility was developed with mining research in mind, it also serves as an ideal facility for the study of a wide range of explosion or fire phenomena in underground facilities. This state-of-the-art laboratory is located in the rural foothills of the Allegheny Mountains of Pennsylvania, approximately 60 miles southeast of Pittsburgh.

Lake Lynn Laboratory consists of both surface and underground test sites and is sufficiently isolated from residents to allow mine/tunnel fire research and large-scale explosion testing of gases, dusts, and chemicals (see Figures 1-1 and 1-2). The facility was built at an abandoned commercial limestone quarry, where underground entries 15 m wide by 10 m high were developed when surface mining ceased in the late 1960's. From these old workings, the Bureau developed a total of 2,300 m of 6-m wide by 2-m high entries. These entries, in conjunction with the novel use of two explosion-proof bulkhead doors that can be positioned to open or close an entry, can be configured to simulate a wide range of underground activities, ranging from mining to military.

The effectiveness of an explosion in destruction of an underground facility is greatly affected by geometry. A knowledge of how the blast wave produced by a high explosive or a fuel-air explosive is affected by distance down the tunnel, the presence of cross tunnels, and obstructions in the tunnel is essential to the design of more effective weapons in the future. Toward this end, we conducted a series of large-scale tests of propylene oxide/air and high explosive in both the underground and facilities at Lake Lynn Laboratory. This report documents three of the tests in the underground facilities.

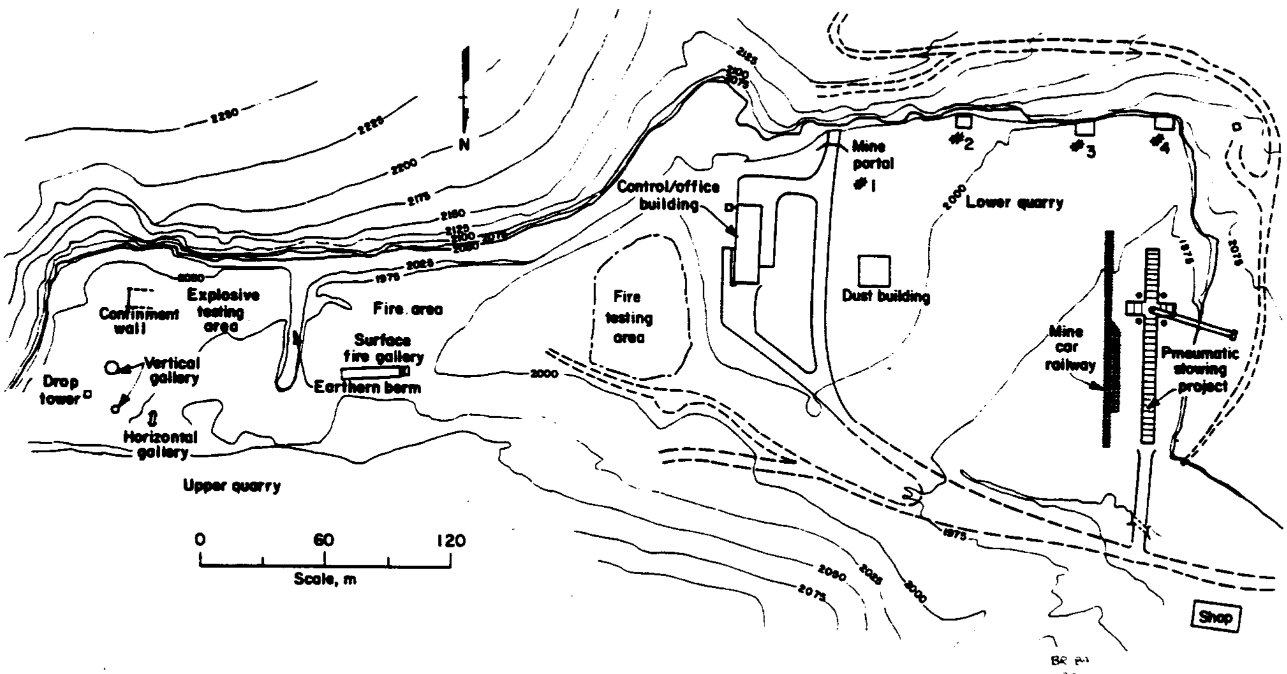

Figure 1-1. Plan view of the surface research areas at the Bureau of Mines' Lake Lynn Laboratory. The facility is located about 50 miles south of Pittsburgh, Pennsylvania.

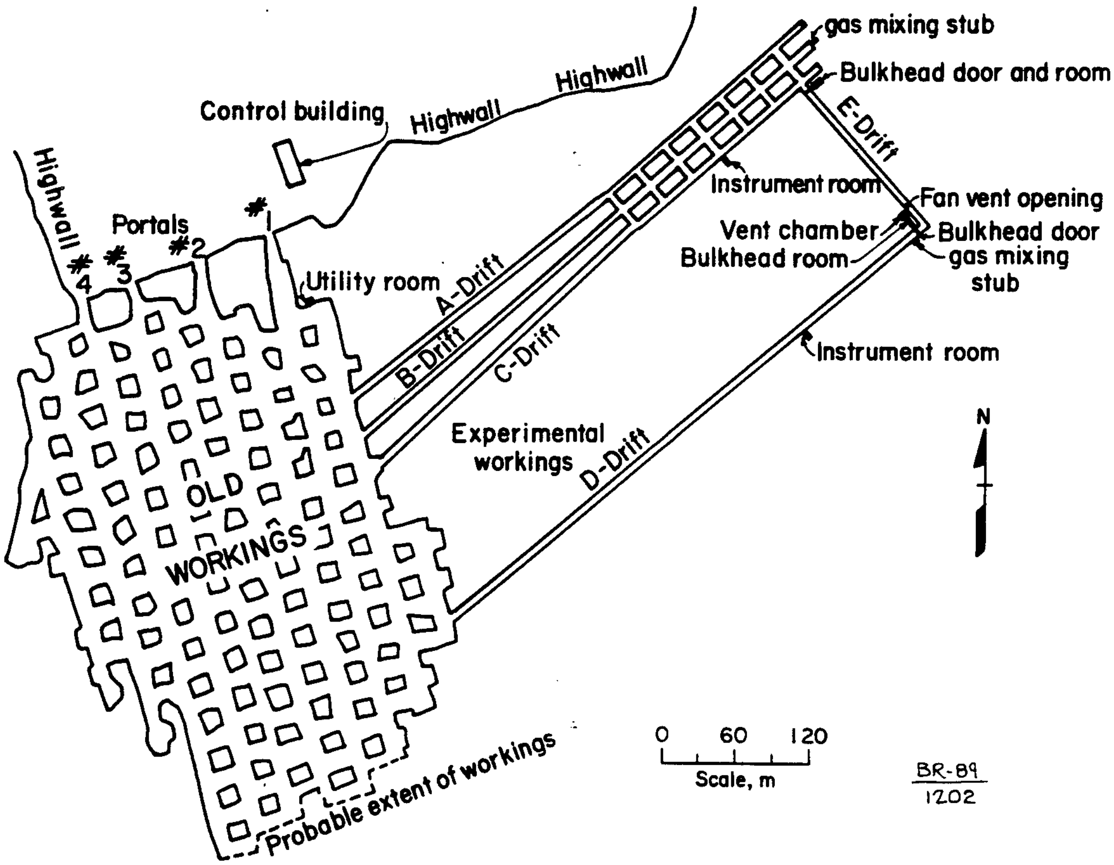

Figure 1-2. Plan view of the underground facilities at Lake Lynn Laboratory.

SECTION 2

EXPERIMENTAL

2.1 TEST GEOMETRY.

For the explosive tests in the underground facilities, two shot locations were selected, the dead-end of A-drift and the intersection of A- and E-drifts. These locations were chosen because they both allowed us to observe propagation of the blast wave through the branching tunnels in the room and pillar section of the facility and also allowed us to observe the difference between a detonation in the dead end of a tunnel and at an intersection where the blast wave can propagate in three directions. These two locations are illustrated in Figure 2-1.

Three different explosives were studied; a stoichiometric mixture of propylene oxide and air, TNT, and C4. We initially planned to shoot equal weights of propylene oxide and TNT to get a comparison of their blast effects. Conducting the experiments using TNT proved to be a problem, however, because we were unable to cast TNT charges within the time frame available for the research and we felt that shooting packages of flaked TNT might not yield reproducible results. We therefore decided to substitute C4 for TNT. C4 yields a higher peak pressure than TNT so the weight of C4 that yields a peak pressure equivalent to a given weight of TNT was determined based on the relationship that peak pressure is proportional to heat of detonation[1]. The heat of detonation for C4 is 1.40 kcal/g and the heat of detonation for TNT is 1.02 kcal/g, yielding a ratio of 1.02/1.40=0.72.[2] Thus, 3.6 lb of C4 was substituted for 5 lb of TNT, 7.2 lb of C4 was substituted for 10 lb of TNT, etc. At each of the two locations 10 and 20 lb charges of propylene oxide, and 3.6, 7.2, and 14.4 lb charges of C4 were detonated. In addition, a 28.8-lb C4 charge was detonated at the dead end of A-drift to obtain data on a larger charge, and a 10-lb charge of TNT was detonated at the intersection of A- and E-drift to serve as a comparison to the 7.2-lb C4 charge; i.e. was 7.2 lb of C4 equivalent to 10 lb of TNT?

A number of explosive shots were also conducted in the surface quarry area of Lake Lynn Laboratory to allow us to perfect our techniques for handling propylene oxide in a more user-friendly environment and to provide data on blast wave propagation in open air. These tests involved shots of 10 lb of propylene oxide, 10 lb of TNT, and 7.2 lb of C4. The surface and underground tests are summarized in Table 2-1.

The tests involving propylene oxide were conducted in a manner representing the ideal FAE detonation, i.e. complete dispersion/vaporization of the fuel and intimate mixing with air. To this end, the detonations of propylene oxide were carried out in a wood and plastic chamber constructed at the shot location. Prior to the test, the propylene oxide was loaded into a steel

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[1]Engineering Design Handbook, Principles of Explosive Behavior, AMC Pamphlet AMCP 706-180, Headquarters, U.S. Army Material Command, April, 1972, p 3-5.

[2]Dobratz, B.M. and P.C. Crawford, LLNL Explosives Handbook: Properties of Chemical Explosives and Explosive Simulants, Lawrence Livermore National Laboratory, Livermore, CA, January 31, 1985.

vessel fitted with remotely operated solenoid valves; the vessel is illustrated in Figure 2-2. In preparation for a test the valves were opened and the vessel was pressurized to 100 psi with nitrogen. The propylene oxide flowed through a plastic tube to a nozzle mounted in the wood and plastic chamber where it sprayed out as fine droplets. When all of the propylene oxide had been sprayed into the chamber, the fuel/air atmosphere was circulated by an expendable electric fan for two minutes to ensure total vaporization and mixing. The propylene oxide/air mixture was then initiated by the detonation of 100 g of C4 suspended in the center of the chamber. Figure 2-3 illustrates the wood and plastic chamber being prepared for a shot and Figure 2-4 shows the inside of the chamber.

2.2 INSTRUMENTATION.

Pressure pulses were recorded using PCB Piezotronic Model 102A04 pressure transducers having a range of 0-1000 psi with a rise time of 1 microsecond, and strain-gauge type pressure transducers permanently mounted in the underground facilities for the study of gas explosions. The strain guage type pressure transducers were Genisco Model SP500 (now Patriot Sensors) and Dynisco Model APT380DV-1C-C29. The location and identification of the pressure transducers are illustrated in Figures 2-5 and 2-6, with identification of the Genisco and Dynisco transducers detailed in Table 2-2. The Genisco and Dynisco transducers were connected to the computer room in the surface control building where the data was digitized and stored. The PCB Piezotronic pressure transducers were connected to data collection instrumentation and a computer in the instrumentation room. The slow response time of the Genisco and Dynisco pressure transducers (in the range of 0.2 to 0.5 ms) and the 1500 hertz sampling rate make the value of their output questionable but the data have been included for completeness.

For the surface tests and some of the underground test, a Low Cam and standard video cameras were set up to record the detonation. The Low Cam was operated at 250 or 500 frames/sec. The cameras proved to be of limited value in studying the underground shots since dust raised by the detonation quickly obscured the camera's view of the event.

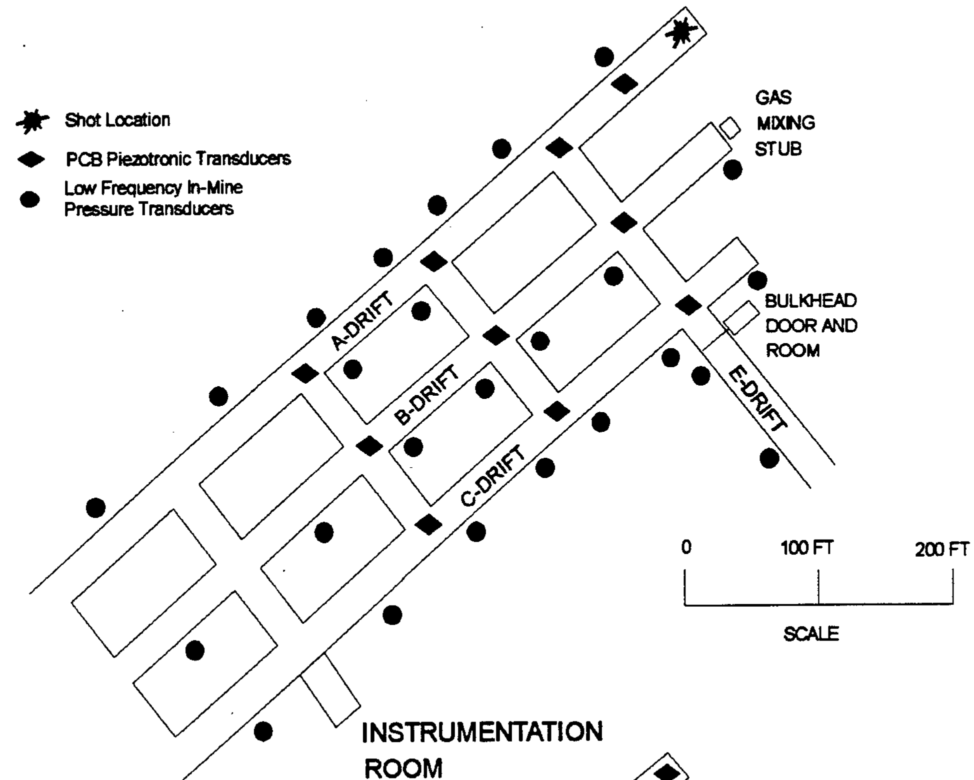
Table 2-1. Summary of tests.

Shot Number	Shot Location	Explosive	Comments
1	End of A-Drift	3.6 lb C4	Equivalent to 5 lb TNT
2	End of A-Drift	7.2 lb C4	Equivalent to 10 lb TNT
3	End of A-Drift	14.4 lb C4	Equivalent to 20 lb TNT
4	Intersection[1]	3.6 lb C4	Equivalent to 5 lb TNT
5	Intersection	7.2 lb C4	Equivalent to 10 lb TNT
6	Intersection	14.4 lb C4	Equivalent to 20 lb TNT
7	Intersection	10 lb TNT	
8	End of A-Drift	28.8 lb C4	Equivalent to 40 lb TNT
9	Surface Quarry	2.5 lb P.O. (?)[2]	Difficulties in Dispersal
10	Surface Quarry	3.6 lb C4	Equivalent to 5 lb TNT
11	Surface Quarry	5 lb TNT	
12	End of A-Drift	5 lb P.O. (?)	Difficulties in Dispersal
13	End of A-Drift	10 lb P.O. (?)	Difficulties in Dispersal
14	End of A-Drift	20 lb P.O.	Good Dispersal
15	End of A-Drift	10 lb P.O.	Good Dispersal
16	Intersection	10 lb P.O.	Good Dispersal
17	Intersection	20 lb P.O.	Good Dispersal
18	Surface Quarry	10 lb P.O.	Good Dispersal
19	Surface Quarry	10 lb TNT	
20	Surface Quarry	7.2 lb C4	Equivalent to 10 lb TNT

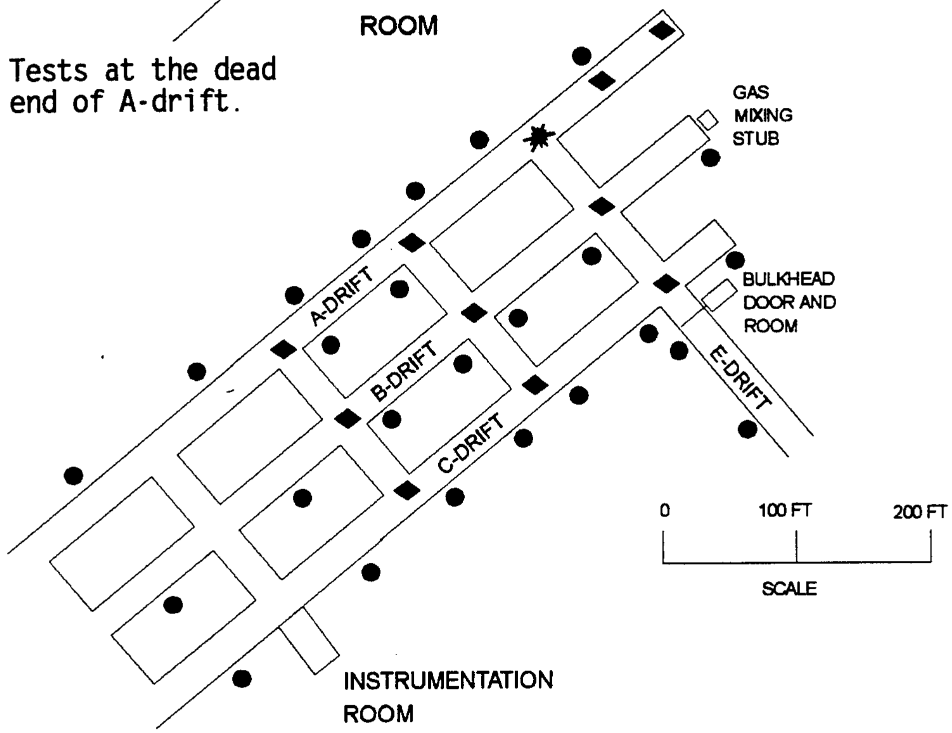
[1]Intersection of A- and E-Drifts
[2]In the earlier shots of propylene oxide (P.O.), we encountered difficulties with dispersal; only half the contents of our vessel was sprayed into the chamber. This problem was corrected in later shots and the questionable shots were repeated.

Table 2-2. Permanently mounted pressure transducers at Lake Lynn Laboratory.

DESIGNATION	LOCATION	DISTANCE FROM FACE, FT	MANUFACTURER	MODEL
A-1	A-drift	22	Genisco	SP500
A-2	A-drift	132	Genisco	SP500
A-3	A-drift	183	Genisco	SP500
A-4	A-drift	233	Genisco	SP500
A-5	A-drift	283	Genisco	SP500
A-6	A-drift	355	Genisco	SP500
A-7	A-drift	453	Genisco	SP500
A-8	A-drift	550	Genisco	SP500
A-9	A-drift	649	Genisco	SP500
A-10	A-drift	807	Gensico	SP500
B-1	B-drift	10	Genisco	SP500
B-2	B-drift	108	Genisco	SP500-23
B-3	B-drift	158	Dynisco	APT380DV-1C-C29
B-4	B-drift	211	Dynisco	APT380DV-1C-C29
B-5	B-drift	257	Dynisco	APT380DV-1C-C29
B-6	B-drift	329	Genisco	SP500
B-7	B-drift	427	Dynisco	APT380DV-1C-C29
B-8	B-drift	526	Dynisco	APT380DV-1C-C29
B-9	B-drift	626	Dynisco	APT380DV-1C-C29
B-10	B-drift	782	Dynisco	APT380CV-1c-C29
C-1	C-drift	13	Genisco	SP500-23
C-2	C-drift	84	Genisco	SP500-23
C-3	C-drift	134	Genisco	SP500-23
C-4	C-drift	184	Genisco	SP500-23
C-5	C-drift	234	Genisco	SP500-23
C-6	C-drift	304	Genisco	SP500-23
C-7	C-drift	403	Genisco	SP500-23
C-8	C-drift	501	Genisco	SP500
C-9	C-drift	598	Genisco	SP500-23
C-10	C-drift	757	Genisco	SP500



(a) Tests at the dead end of A-drift.



(b) Tests at the intersection of A- and E-drifts.

Figure 2-1. Experimental layout for explosive tests in the underground facilities at the Bureau's Lake Lynn Laboratory. Tests were conducted at the dead-end of A-drift, (top) and at the intersection of A- and E-Drift.

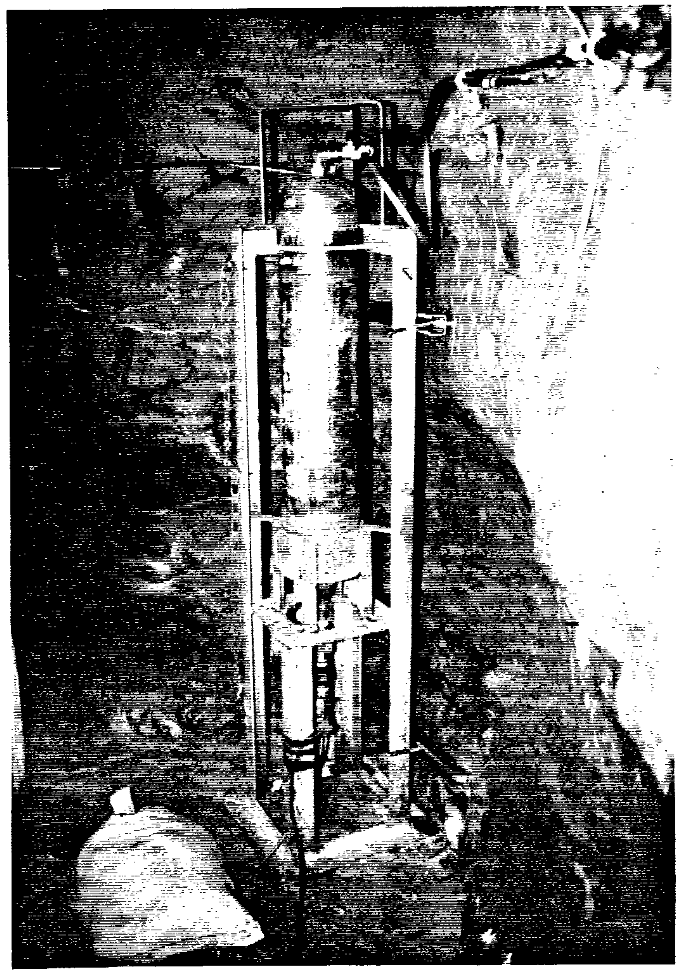


Figure 2-2. Steel vessel containing propylene oxide prior to its dispersal by nitrogen pressure.

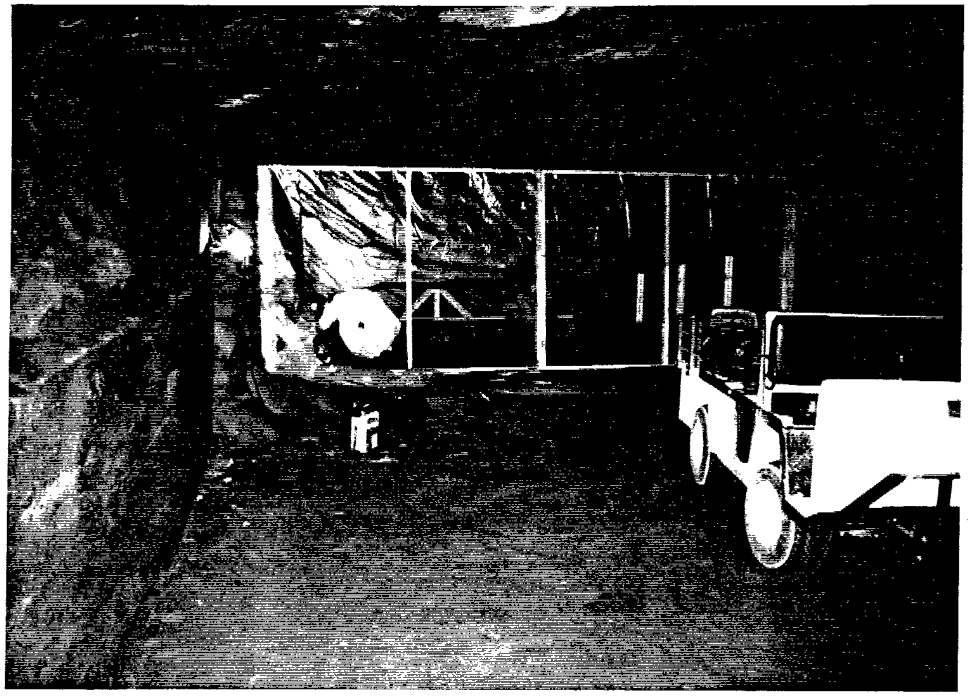


Figure 2-3. Wood and plastic chamber in which propylene oxide was dispersed, mixed with air, and detonated. For the shots of 20 lb pf propylene oxide as stoichiometric fuel/air mixtures, the chamber measured 16 ft, 10 in square and 6 ft high.

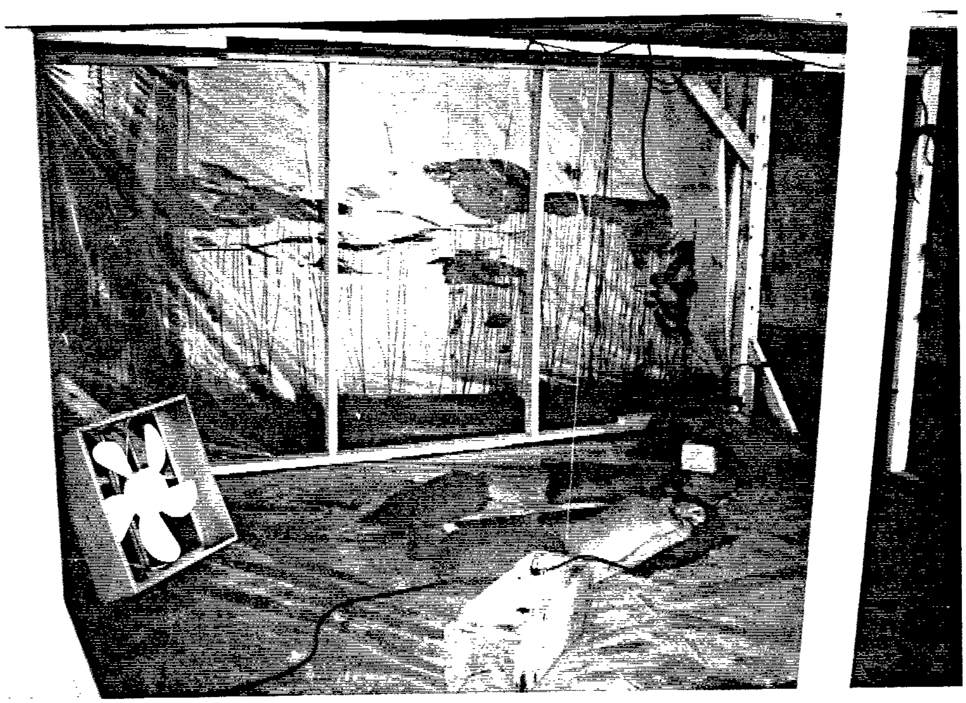


Figure 2-4. Interior view of the wood and plastic chamber.

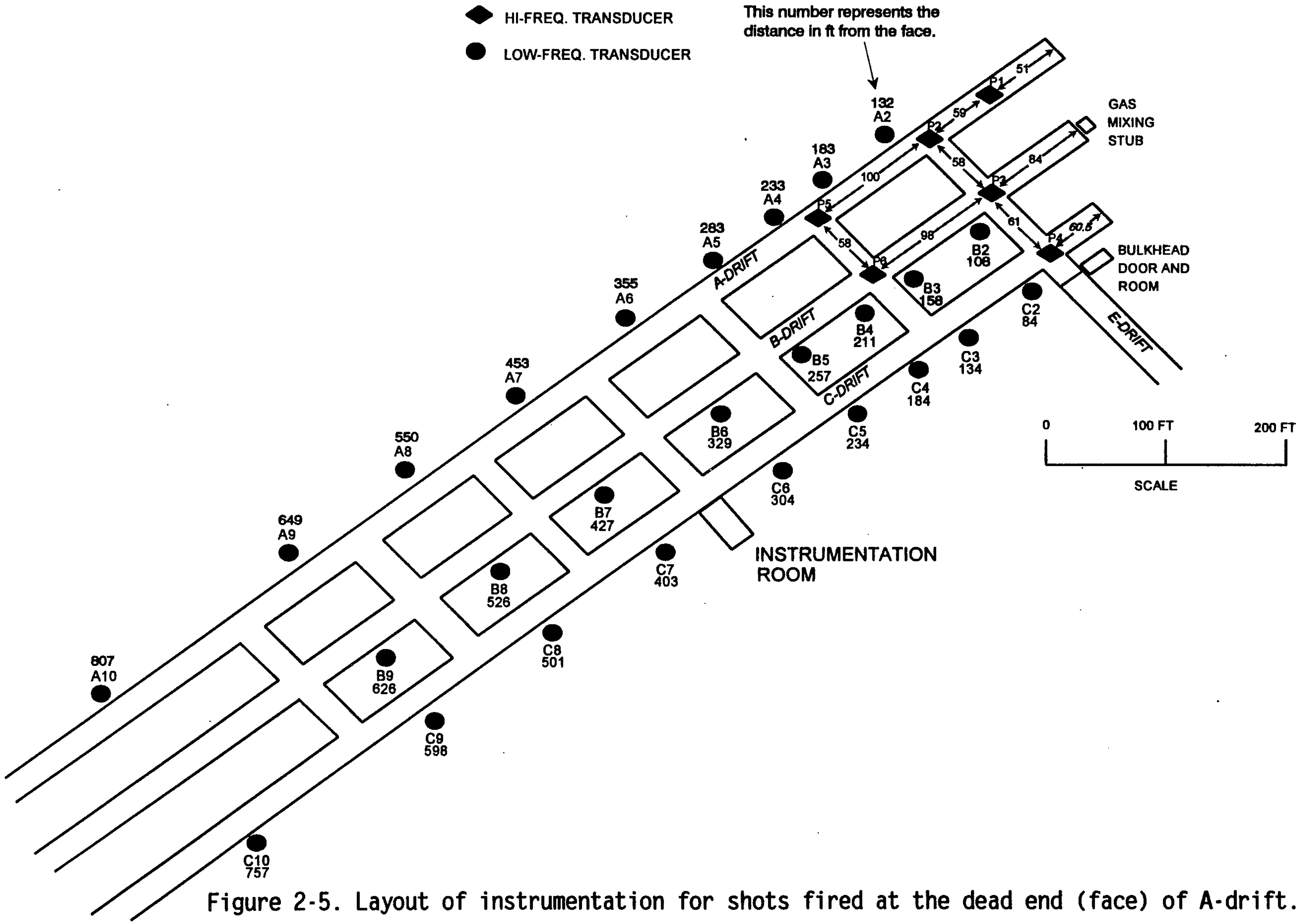


Figure 2-5. Layout of instrumentation for shots fired at the dead end (face) of A-drift.

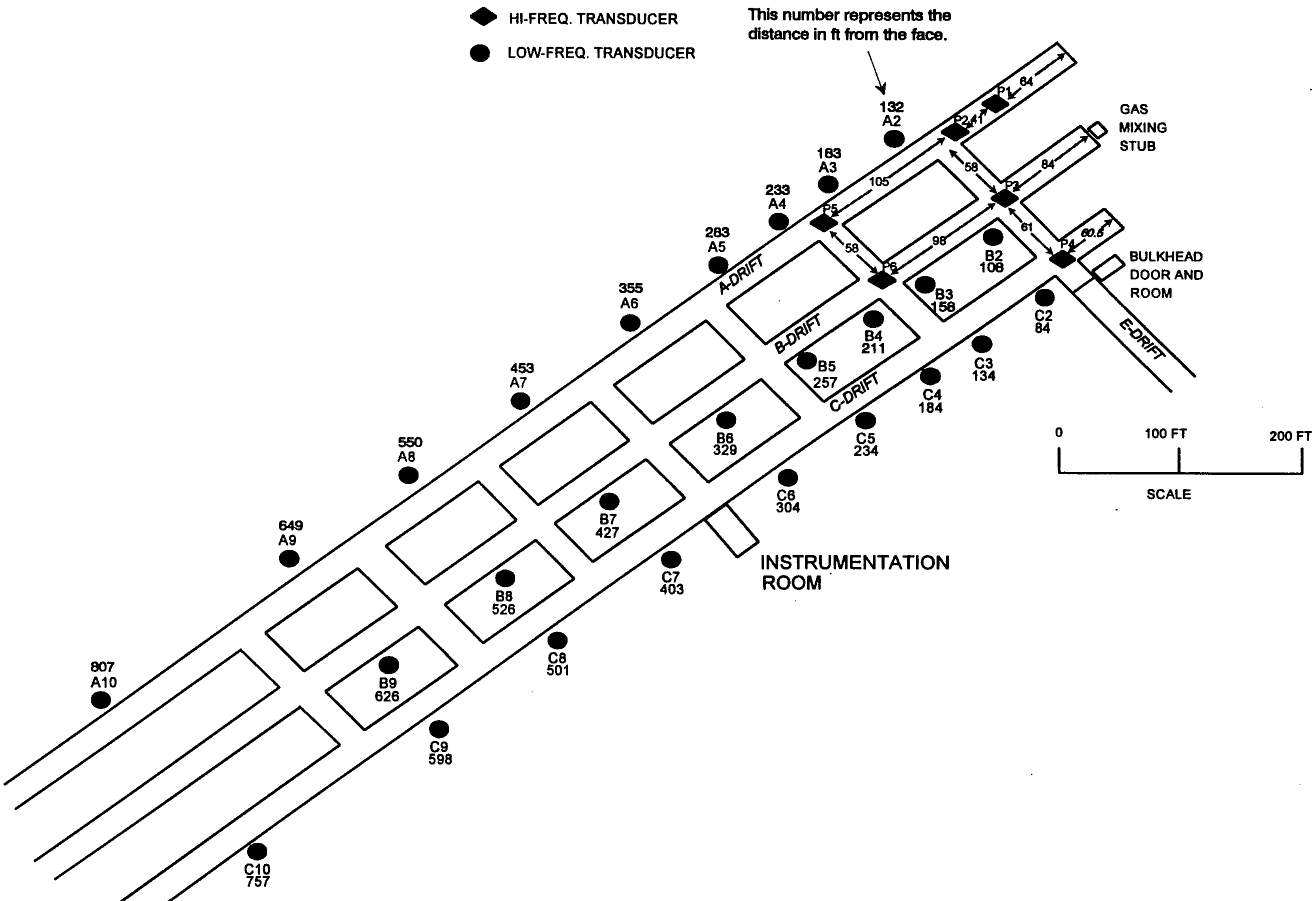


Figure 2-6. Layout of instrumentation for shots fired at the intersection of A- and E-drifts.

SECTION 3

RESULTS

3.1 GENERAL.

Table 2-1 lists a summary of the explosive tests conducted as part of this project. A total of 20 shots were conducted but not all of these are documented here due to limitations of time and resources.

3.2 SHOT NUMBER 8.

Shot Number 8 involved the detonation of 28.8 lb of C4 explosive in the form of a sphere suspended from the roof at the dead end of A-drift. The charge was positioned 5 ft from the face, half way between the roof and floor, and was initiated by a number 8 electric blasting cap.

3.2.1 Instrumentation.

Blast pressures were recorded by two types of pressure transducers: PCB Piezotronic, Model 102A04 Quartz Pressure Transducers designated P1 through P6 and pressure transducers permanently mounted in the mine, labeled A2 through A10, B2 through B9, and C1 through C10 (see Table 2-2). The PCB Piezotronic pressure transducers were mounted on stands constructed of steel pipe positioned in the center of the mine entry with the transducer 3 ft above the floor. Data from these transducers was recorded by six Keithley Metrabyte DAS-50 data acquisition boards operating at a rate of one pressure data point per microsecond. The pressure transducers labeled A2-A10, B2-B9, and C1-C10 were permanently mounted in the mine walls and collected data at a rate of 1500 pressure data points per second.

3.2.2 Computer Data Records.

Data from the PCB Piezotronic transducers, designated P1.ASC through P6.ASC, are stored as lists of pressure data points in PSI in ASCII format. The time interval between data points is one microsecond. The record begins at the initiation of the C4 charge. The pressure data are illustrated in Figures 3-1 through 3-4.

Data from the in-mine pressure transducers, designated A2.ASC through A10.ASC, B2.ASC through B9.ASC, and C1.ASC through C10.ASC are also stored as lists of pressure data points in PSI in ASCII format. The time interval between data points is 0.6667 milliseconds. The record begins at initiation of the 100 gram C4 charge.

3.3 SHOT NUMBER 14.

Shot Number 14 involved the detonation of a stoichiometric mixture of 20 lb of propylene oxide in air. The propylene oxide was sprayed into a wood and plastic chamber measuring 16 ft, 10 in by 16 ft, 10 in by 6 ft high. The chamber was located at the dead end of A-drift; see Figure 2-1. An electric fan within the chamber circulated the mixture for two minutes to ensure that the propylene oxide was vaporized and evenly mixed. The mixture was detonated by a 100 gram charge of C4 suspended in the center of the chamber.

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3.4 SHOT NUMBER 17.

Shot Number 17 involved the detonation of a stoichiometric mixture of 20 lb of propylene oxide in air. The propylene oxide was sprayed into a wood and plastic chamber measuring 16 ft, 10 in by 16 ft, 10 in by 6 ft high. The chamber was located at the intersection of A- and E-drifts; see Figure 2-1. An electric fan within the chamber circulated the mixture for two minutes to ensure that the propylene oxide was vaporized and evenly mixed. The mixture was detonated by a 100 gram charge of C4 suspended in the center of the chamber.

3.4.1 Instrumentation.

Blast pressures were recorded by two types of pressure transducers: PCB Piezotronic, Model 102A04 Quartz Pressure Transducers designated P1 through P6 and pressure transducers permanently mounted in the mine, labeled A2 through A10, B2 through B9, and C1 through C10 (see Table 2-2). The PCB Piezotronic pressure transducers were mounted on stands constructed of steel pipe positioned in the center of the mine entry with the transducer 3 ft above the floor. Data from these transducers was recorded by six Keithley Metrabyte DAS-50 data acquisition boards operating at a rate of one pressure data point per microsecond. The pressure transducers labeled A2-A10, B2-B9, and C1-C10 were permanently mounted in the mine rib and collected data at a rate of 1500 pressure data points per second.

3.4.2 Computer Data Records.

Data from the PCB Piezotronic transducers, designated P1.ASC through P6.ASC are stored as lists of pressure data points in PSI in ASCII format. The time interval between data points is one microsecond. The record begins at initiation of the 100 gram C4 charge.

Data from the in-mine pressure transducers, designated A1.ASC through A10.ASC, B2.ASC through B9.ASC, and C1.ASC through C10.ASC are also stored as lists of pressure data points in PSI in ASCII format. The time interval between data points is 0.6667 milliseconds. The record begins at initiation of the 100 gram C4 charge. The pressure data are illustrated in Figures 3-9 through 3-12.

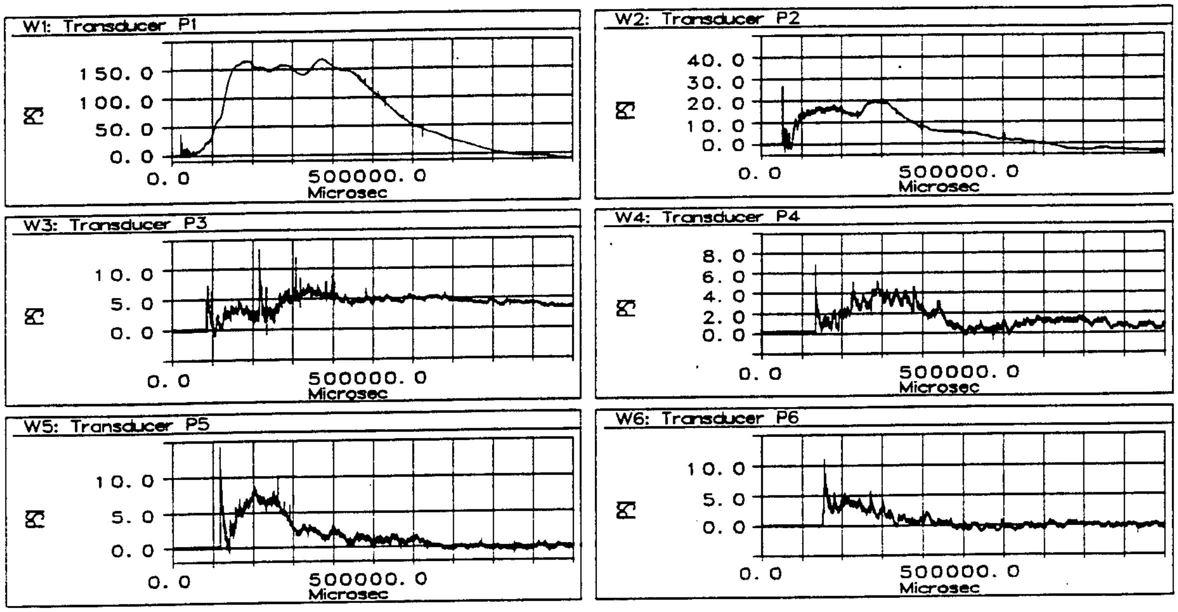
3.4.3 Damage to Witness Targets.

For shot number 17 witness targets were set up to get a better impression of the damage the detonation of 20 lb of propylene oxide would do. The witness targets consisted of desks, chairs, computers, and monitors set up at three locations: 100 feet down A-drift, 200 feet down A-drift, and 60 feet down E-drift. These locations are illustrated in Figure 3-13. Figures 3-14 and 3-15 show the desks, computers, etc. set up 100 ft down A-drift and 60 feet down E-drift, respectively.

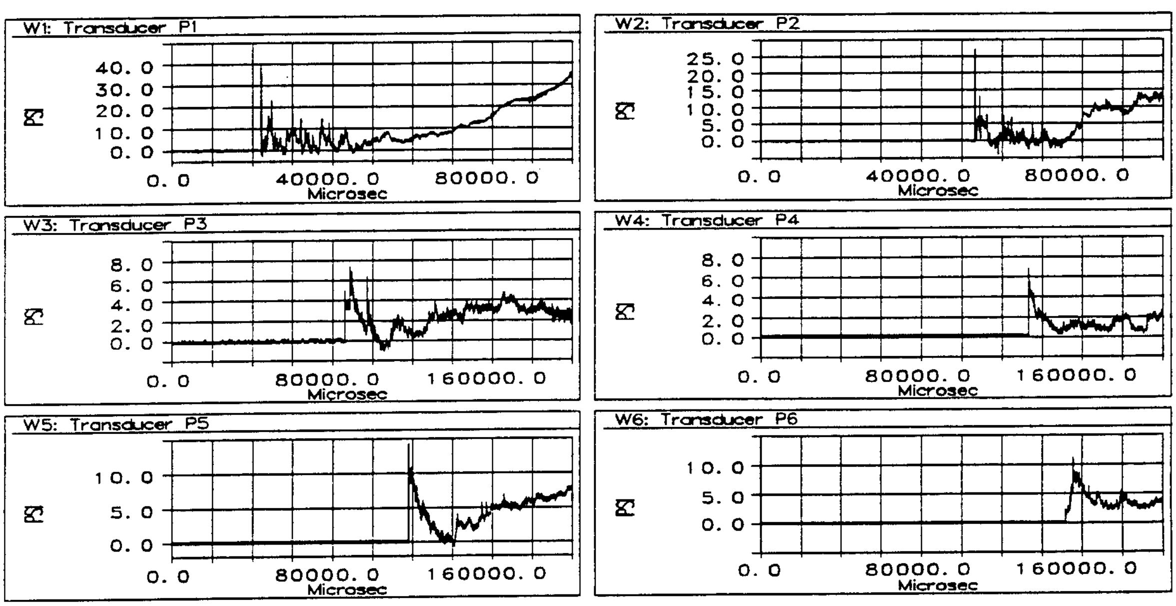
Figures 3-16 through 3-19 show the damage done to the equipment set up 100 ft down A-drift from the detonation. At this location the damage was severe. The desk was ripped apart, the cases on the computer and keyboard were torn open, and the monitor was completely destroyed. The peak pressure measured at this location was 25 psi.

Figures 3-20 through 3-23 illustrate the damage to the equipment located 200 ft down A-drift from the detonation. At this location the desk was dented, the leg bent, and the top separated but the damage wasn't as severe as that observed closer to the detonation. The computer, monitor, and keyboard were thrown to the floor but didn't show any outward signs of damage. The pressure at this location was 9 psi.

Figures 3-24 through 3-28 show the damage to the equipment located 60-feet down E-drift from the detonation. At this location the equipment was not only torn apart but was also strewn around the area; this location represented the most severe damage of the three locations. The case of the computer was torn off and the disk drive was ripped out. All that could be found of the monitor was the plastic base. The pressure measured at this location was 23 psi.

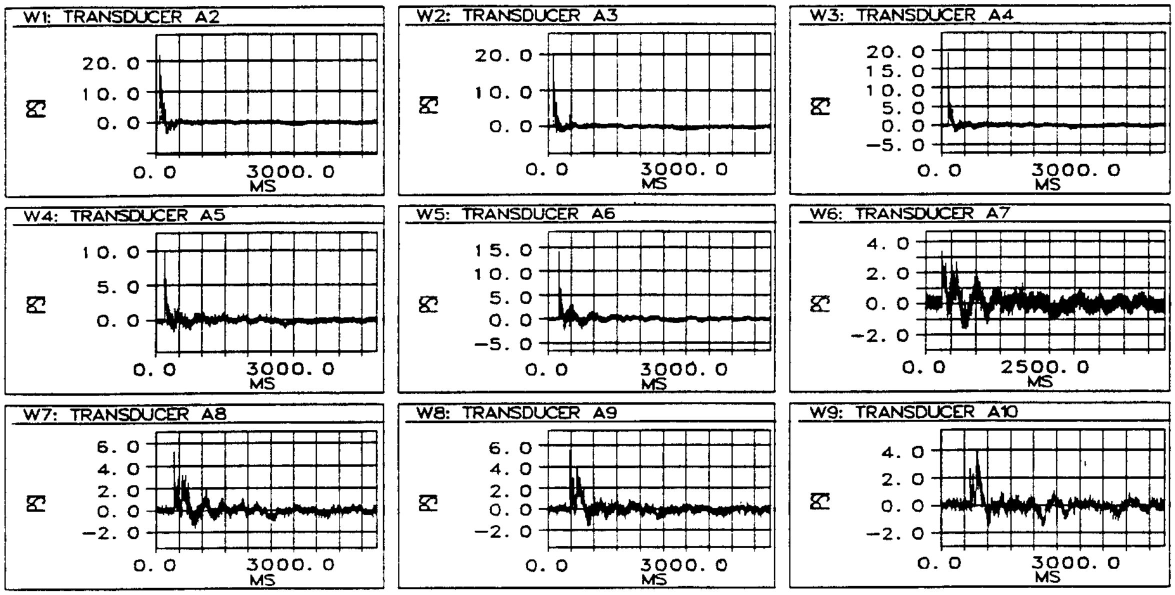


(a) Complete data record



(b) First 100,000 microseconds of data record.

Figure 3-1. Pressure recorded by PCB Piezotronic transducers for shot 8, detonation of 28.8 lb of C4 explosive at the dead end of A-drift.



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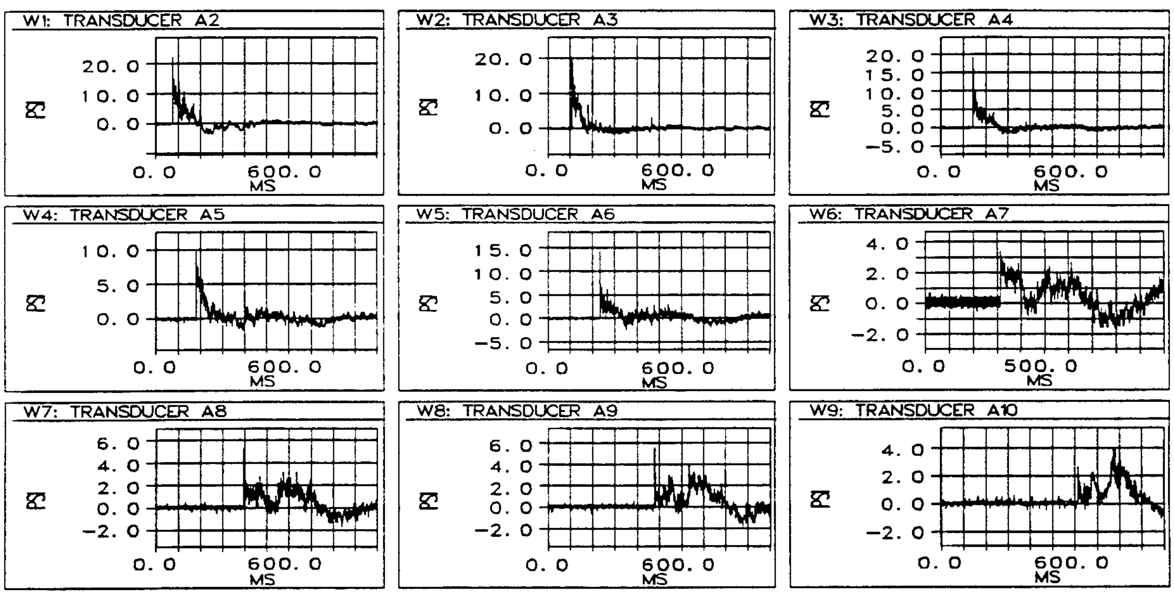
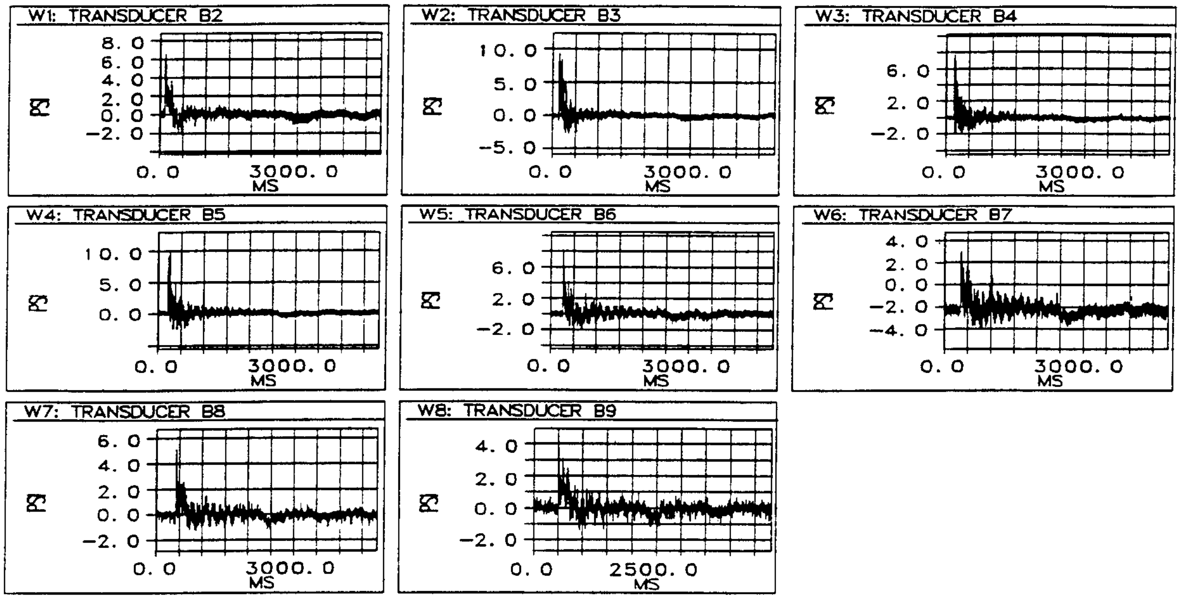


(b) First second of data record.

Figure 3-2. Pressure recorded by in-mine transducers in A-drift for shot 8, detonation of 28.8 lb of C4 explosive at the dead end of A-drift.



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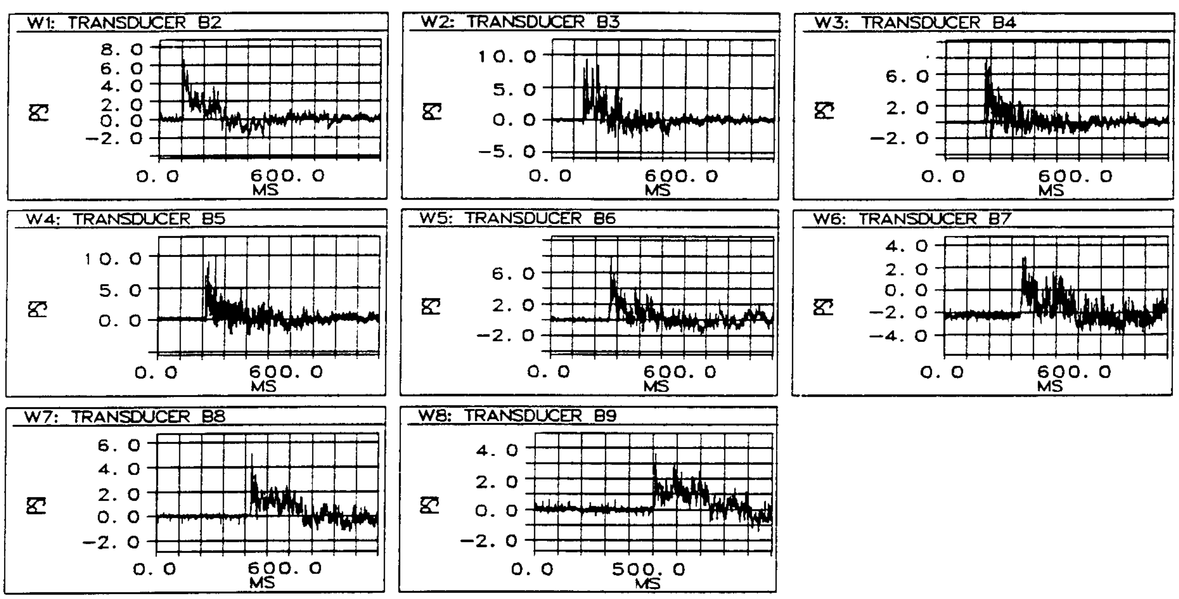
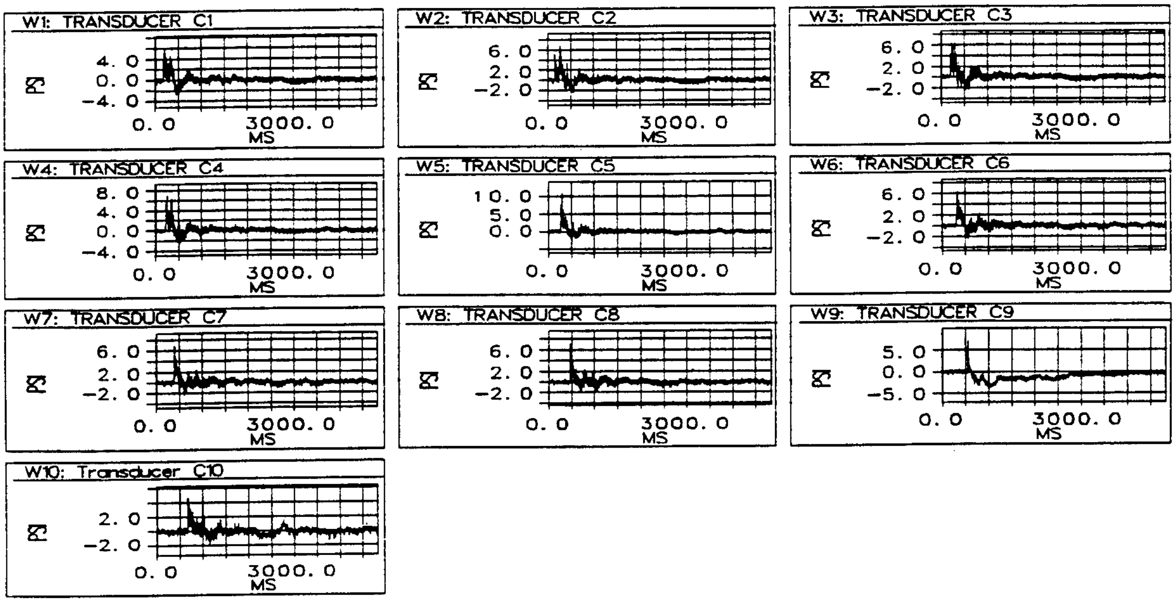
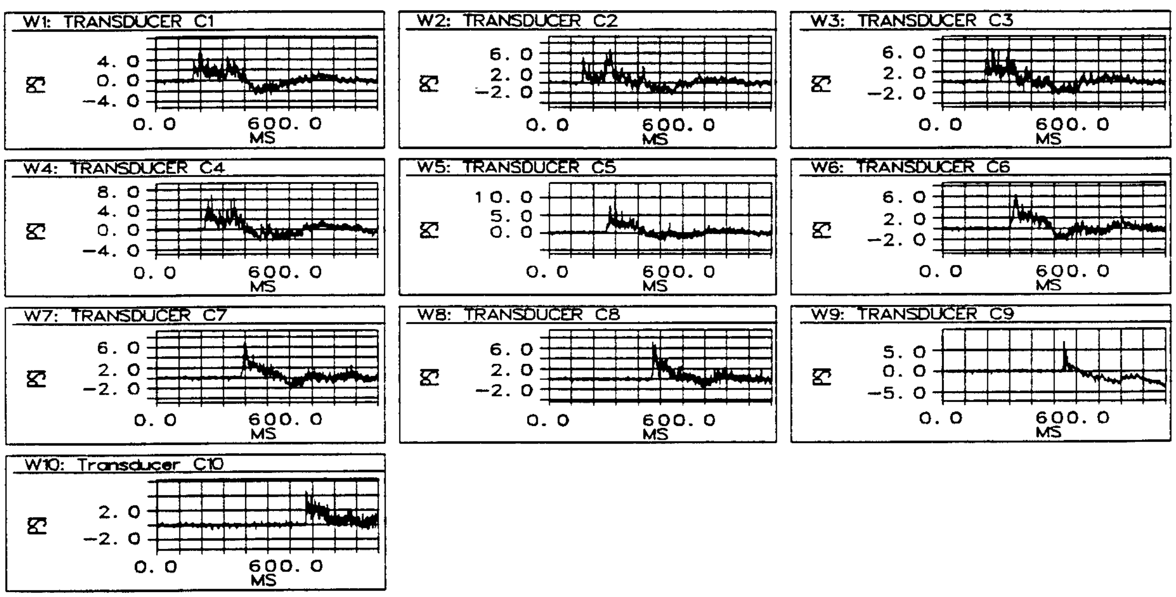


(b) First second of data record.

Figure 3-3. Pressure recorded by in-mine transducers in B-drift for shot 8, detonation of 28.8 lb of C4 explosive at the dead end of A-drift.

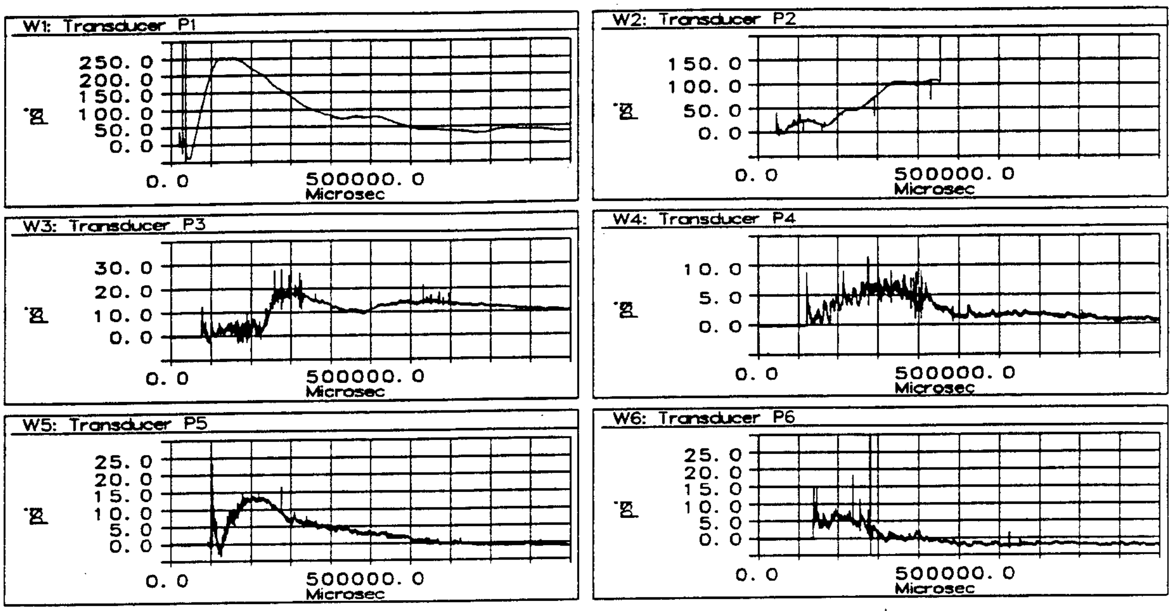


(a) Complete data record

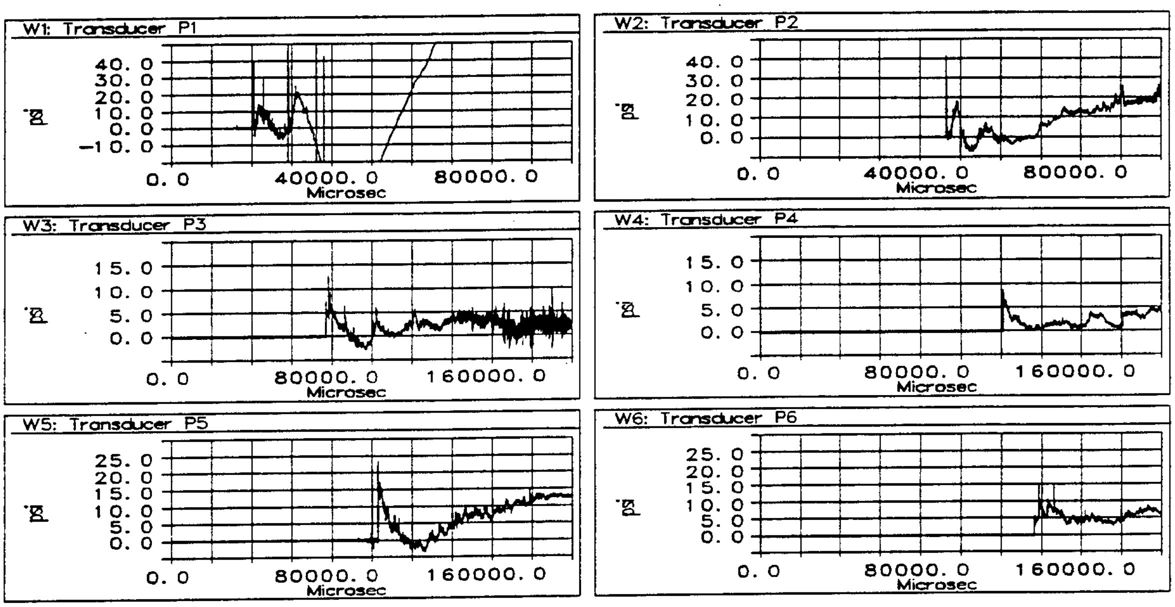


(b) First second of data record.

Figure 3-4. Pressure recorded by in-mine transducers in C-drift for shot 8, detonation of 28.8 lb of C4 explosive at the dead end of A-drift.

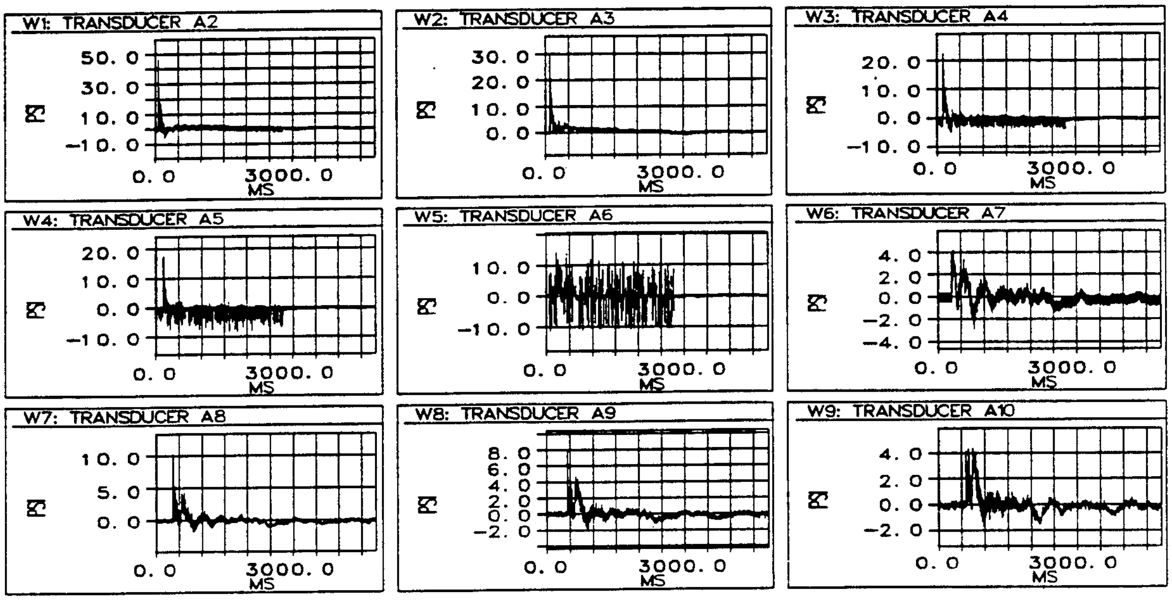


(a) Complete data record

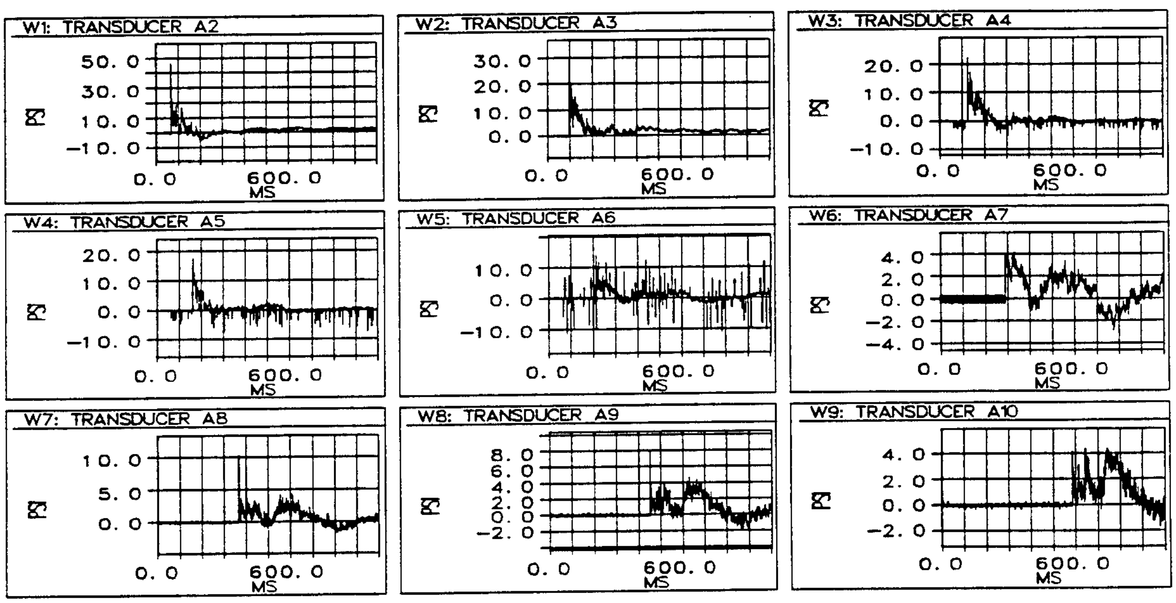


(b) First 100,000 microseconds of data record.

Figure 3-5. Pressure recorded by PCB Piezotronic transducers for shot 14, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the dead end of A-drift.

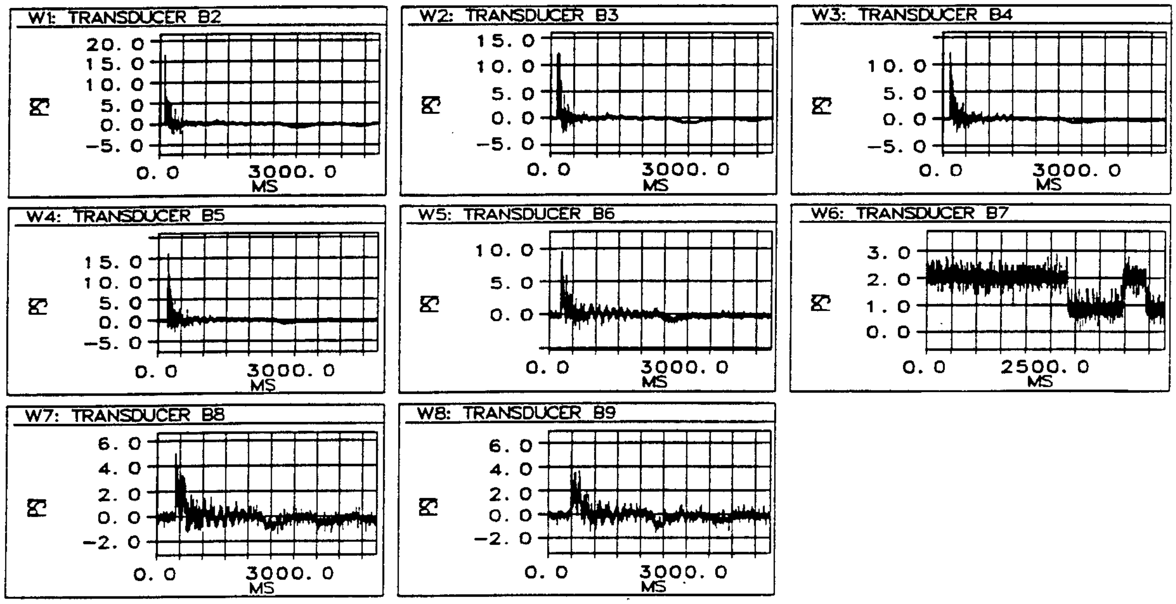


(a) Complete data record

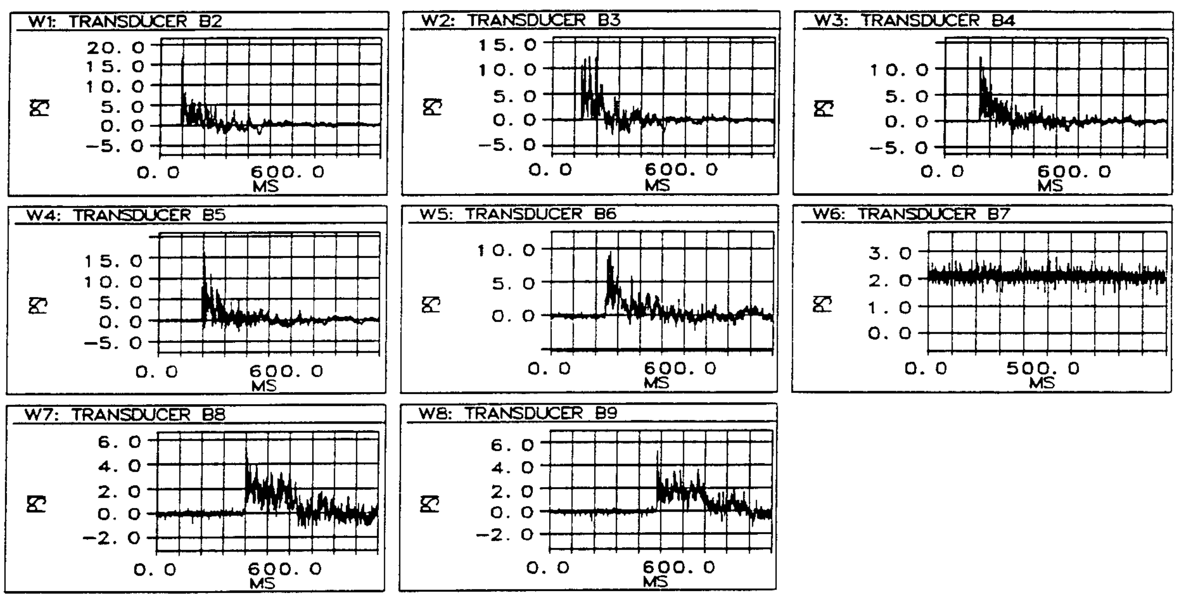


(b) First second of data record.

Figure 3-6. Pressure recorded by in-mine transducers in A-drift for shot 14, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the dead end of A-drift.

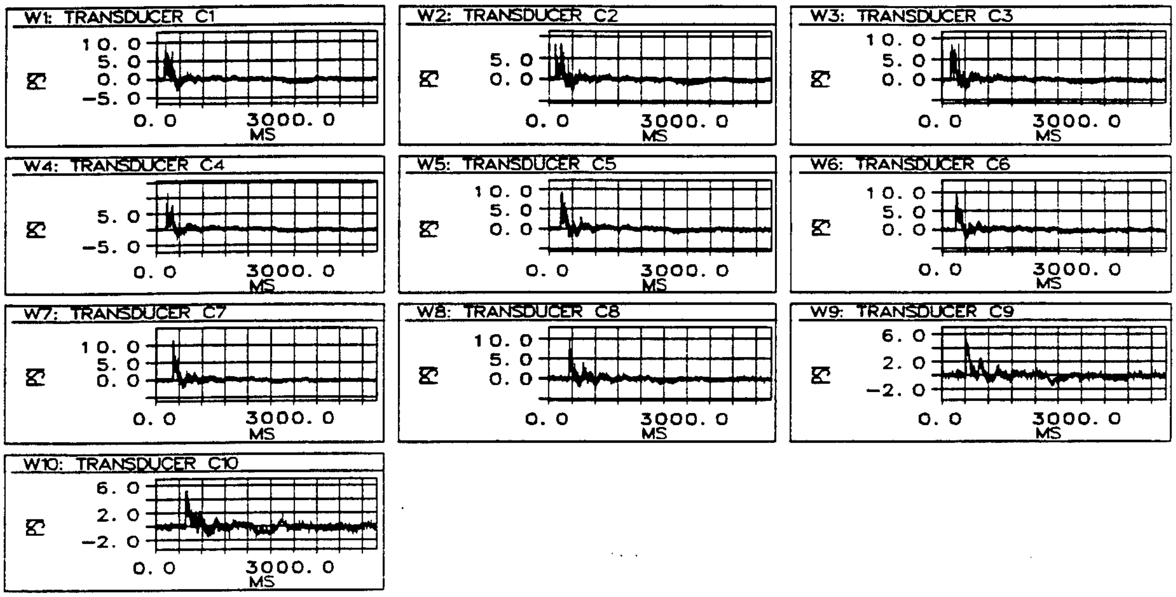


(a) Complete data record

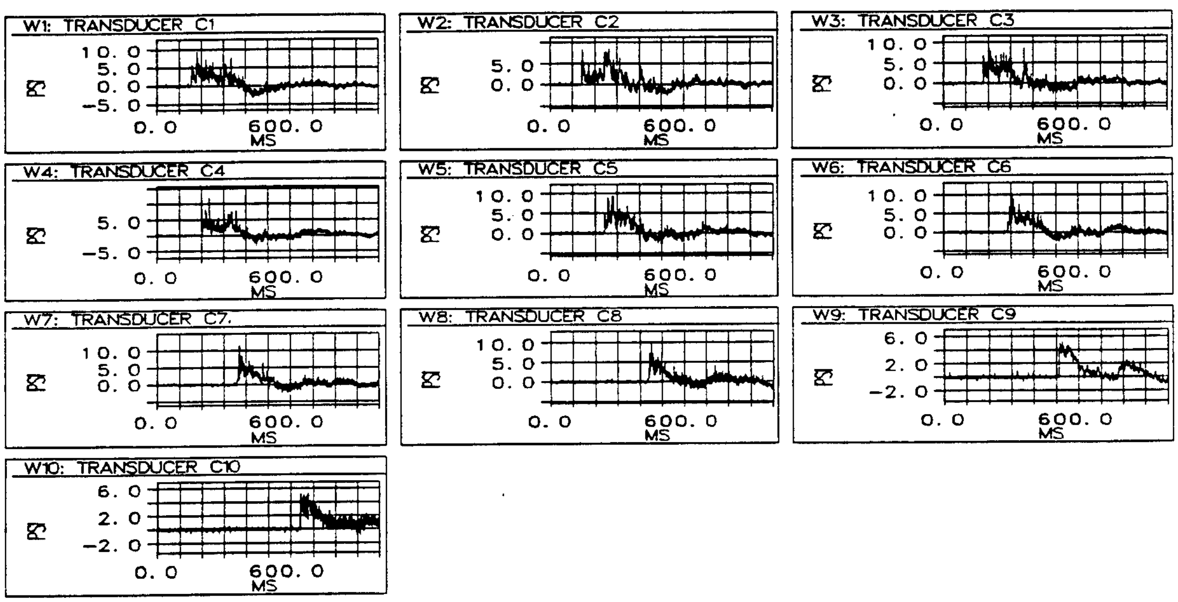


(b) First second of data record.

Figure 3-7. Pressure recorded by in-mine transducers in B-drift for shot 14, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the dead end of A-drift.

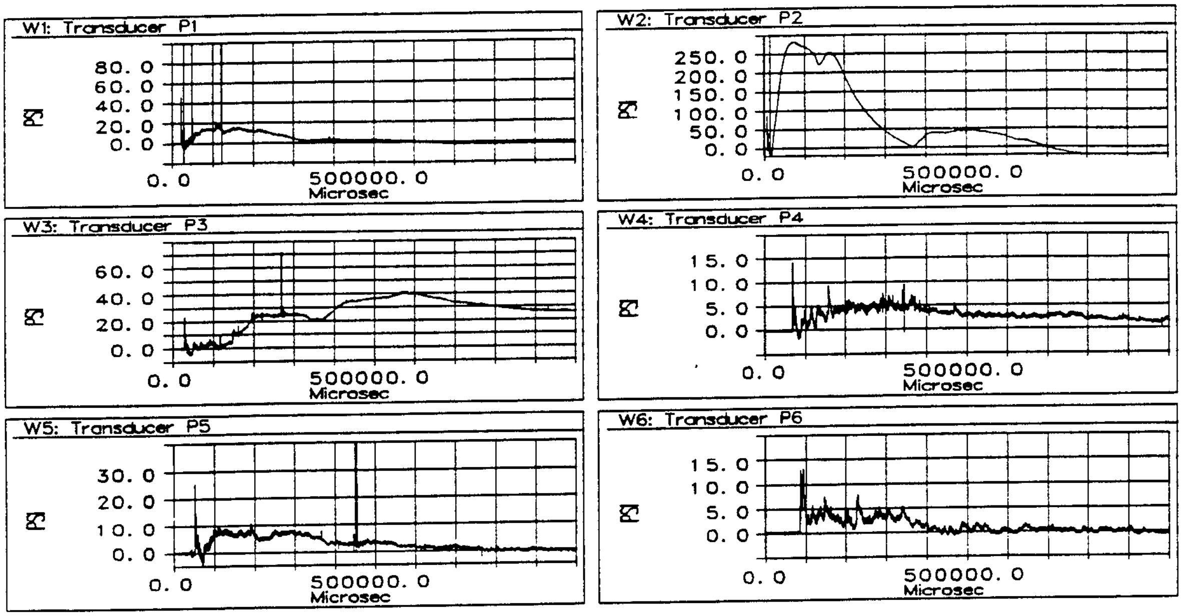


(a) Complete data record

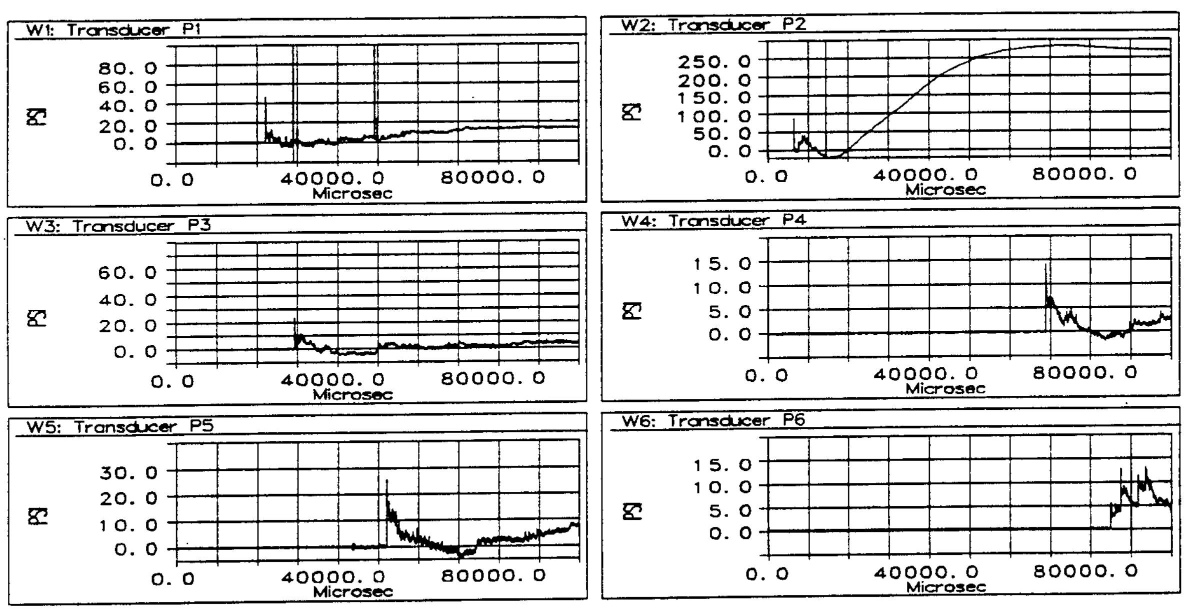


(b) First second of data record.

Figure 3-8. Pressure recorded by in-mine transducers in C-drift for shot 14, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the dead end of A-drift.

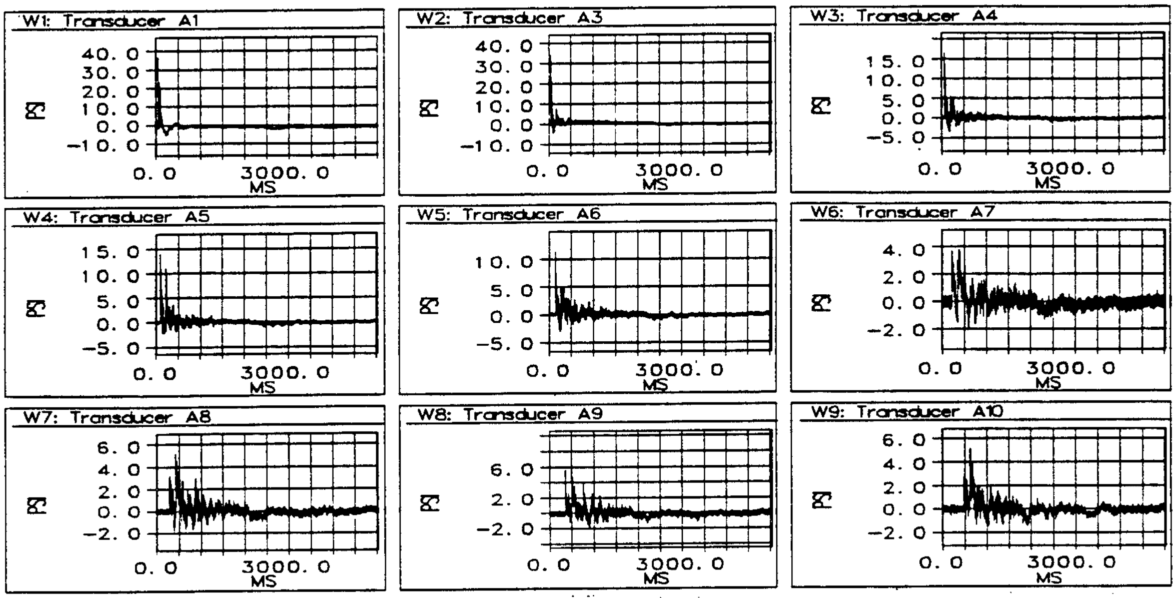


(a) Complete data record

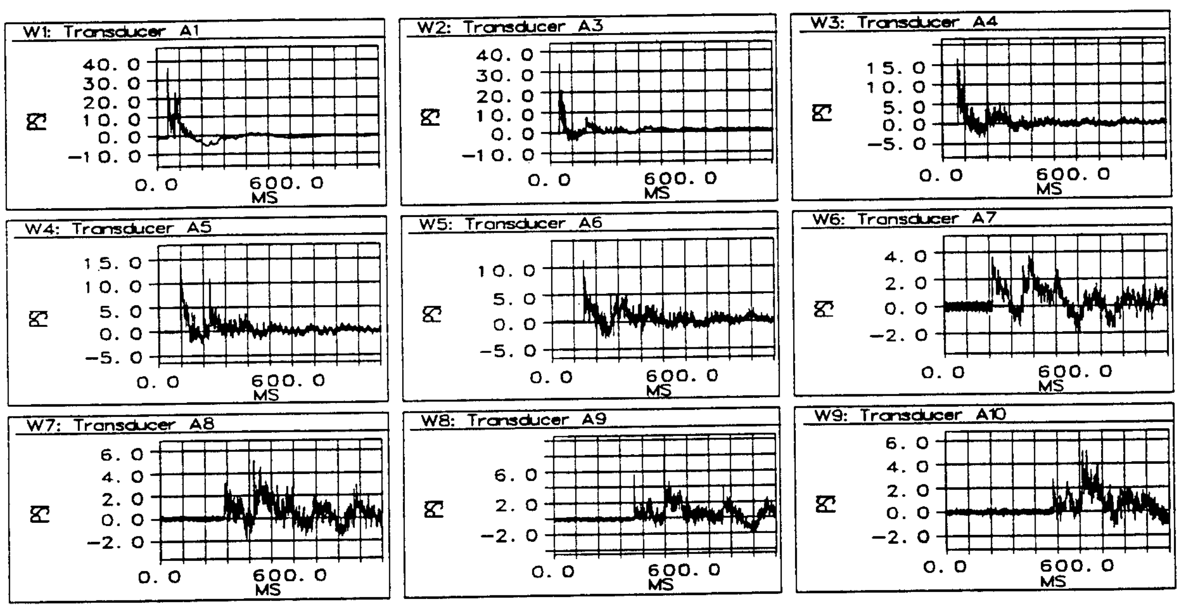


(b) First 100,000 microseconds of data record.

Figure 3-9. Pressure recorded by PCB Piezotronic transducers for shot 17, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the intersection of A- and E-drifts.

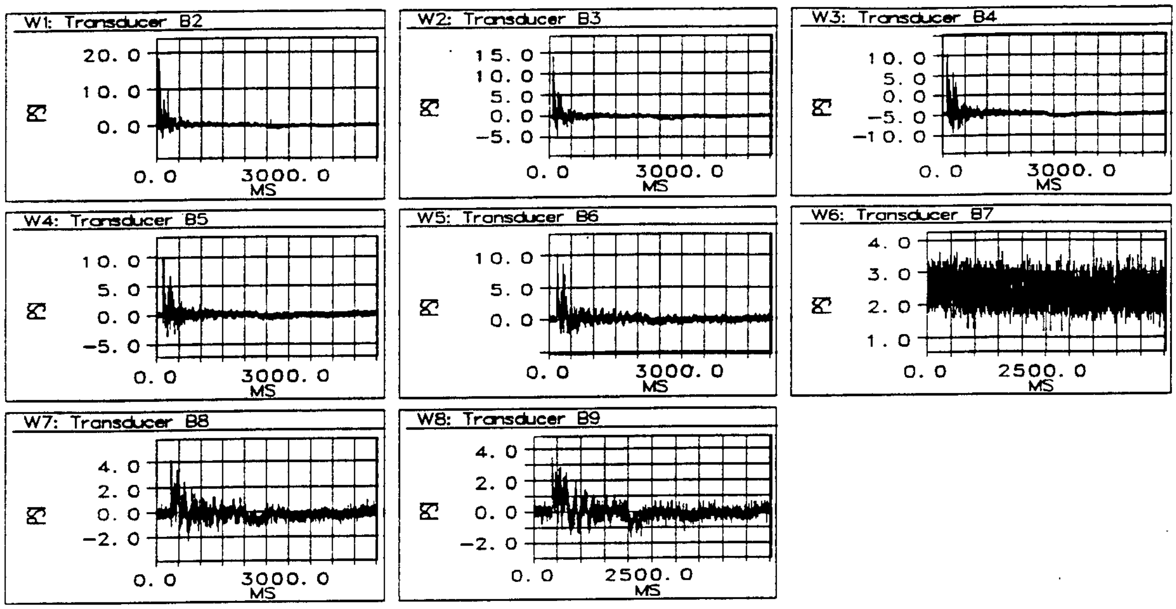


(a) Complete data record

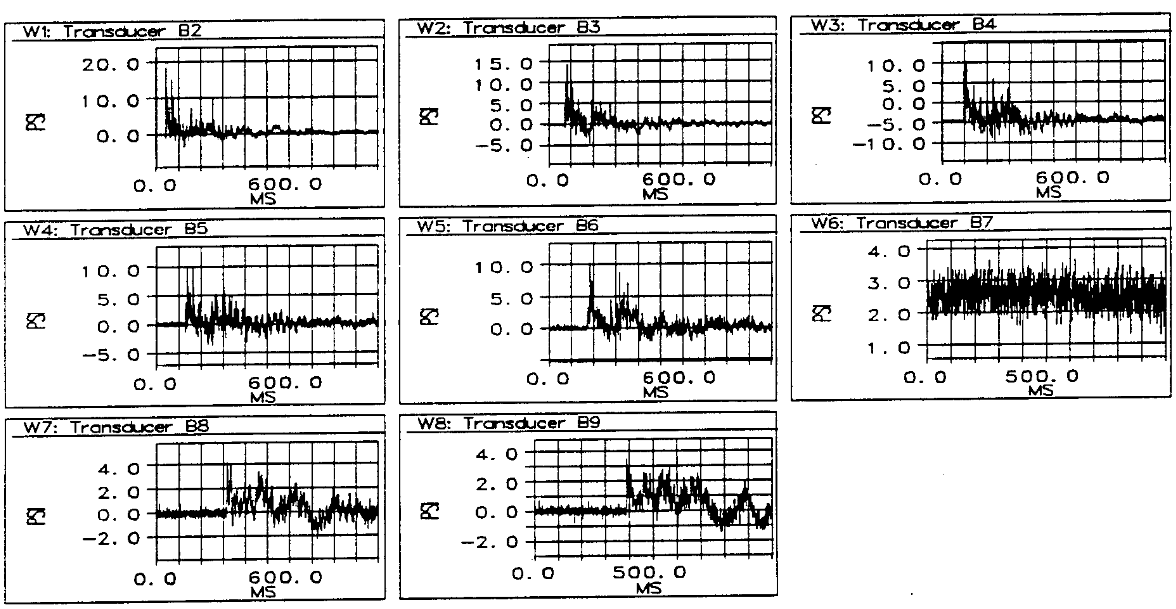


(b) First second of data record.

Figure 3-10. Pressure recorded by in-mine transducers in A-drift for shot 17, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the intersection of A- and E-drifts.

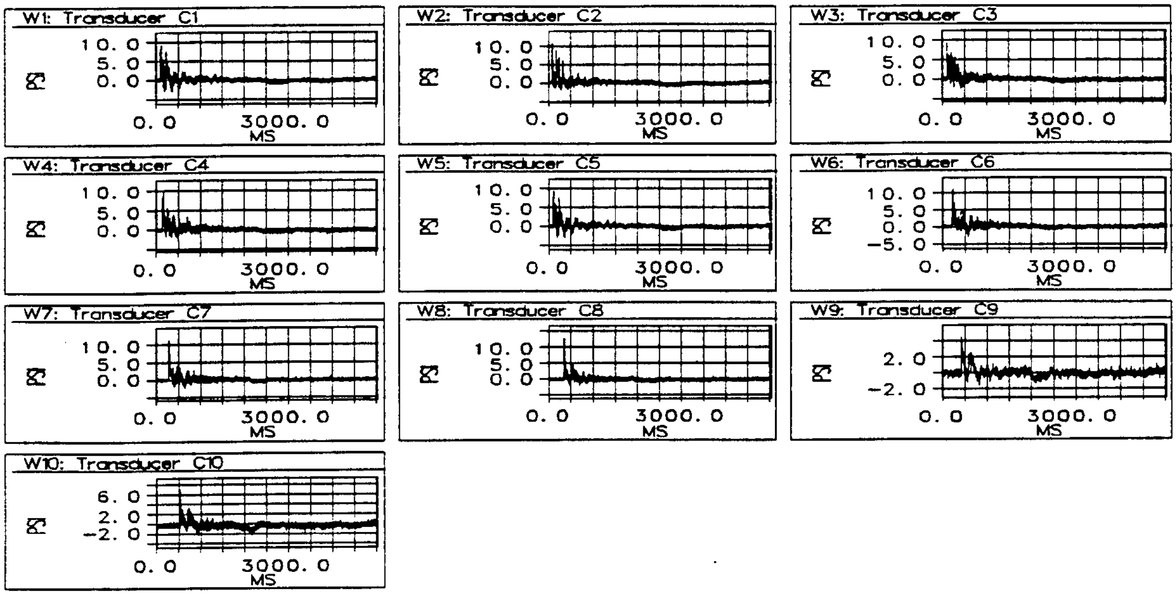


(a) Complete data record

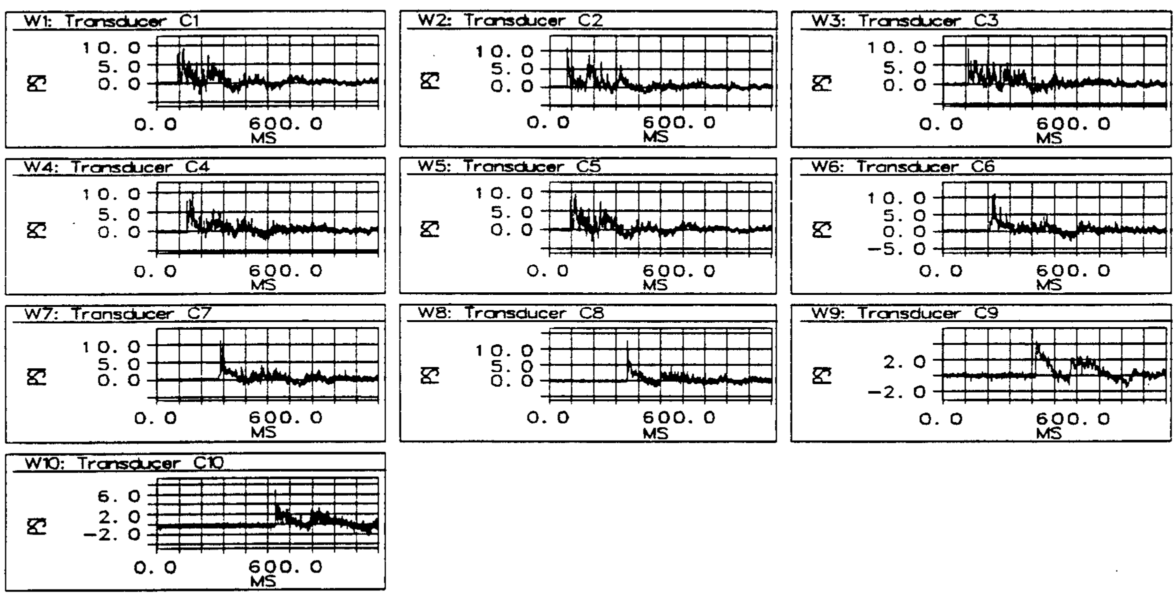


(b) First second of data record.

Figure 3-11. Pressure recorded by in-mine transducers in B-drift for shot 17, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the intersection of A- and E-drifts.



(a) Complete data record



(b) First second of data record.

Figure 3-12. Pressure recorded by in-mine transducers in C-drift for shot 17, detonation of 20 lb of propylene oxide as a stoichiometric fuel/air mixture at the intersection of A- and E-drifts.

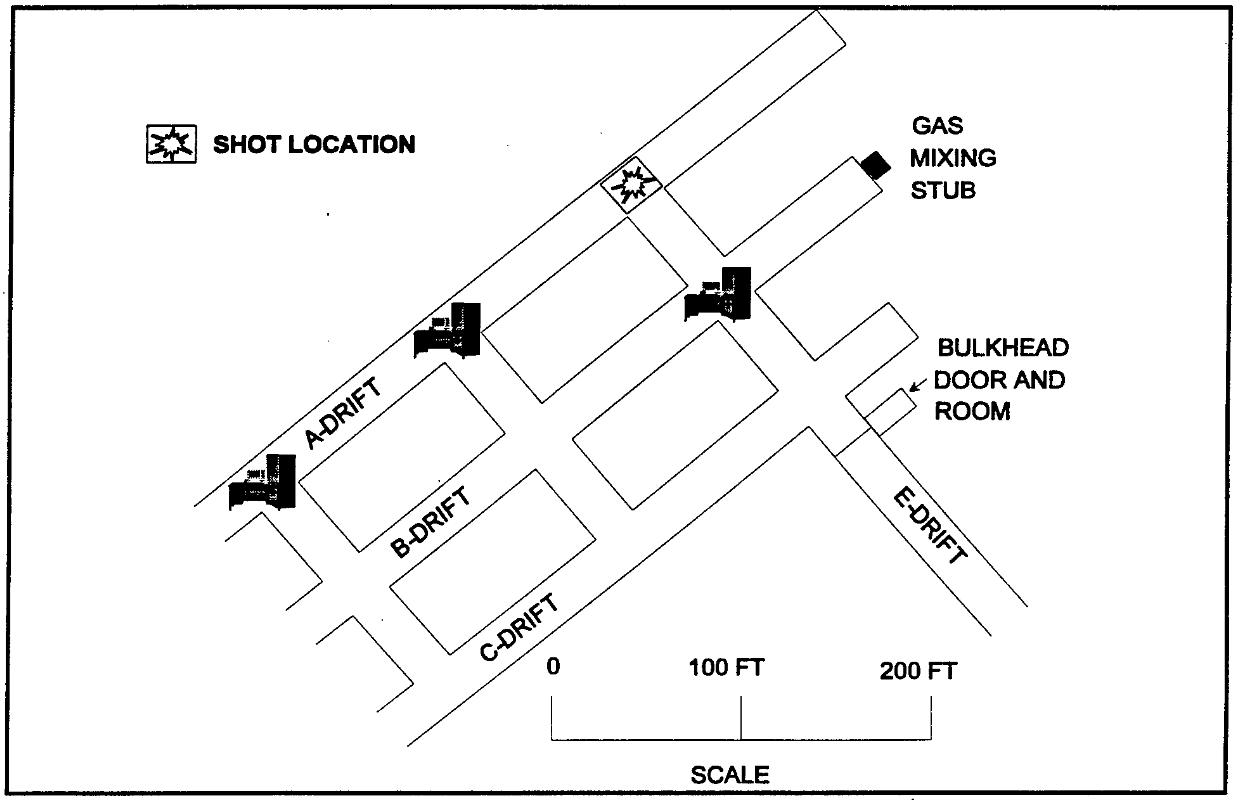


Figure 3-13. Layout of witness targets for Shot Number 17. Targets consisted of desks, chairs, computers, monitors, and filing cabinets set up at three locations.

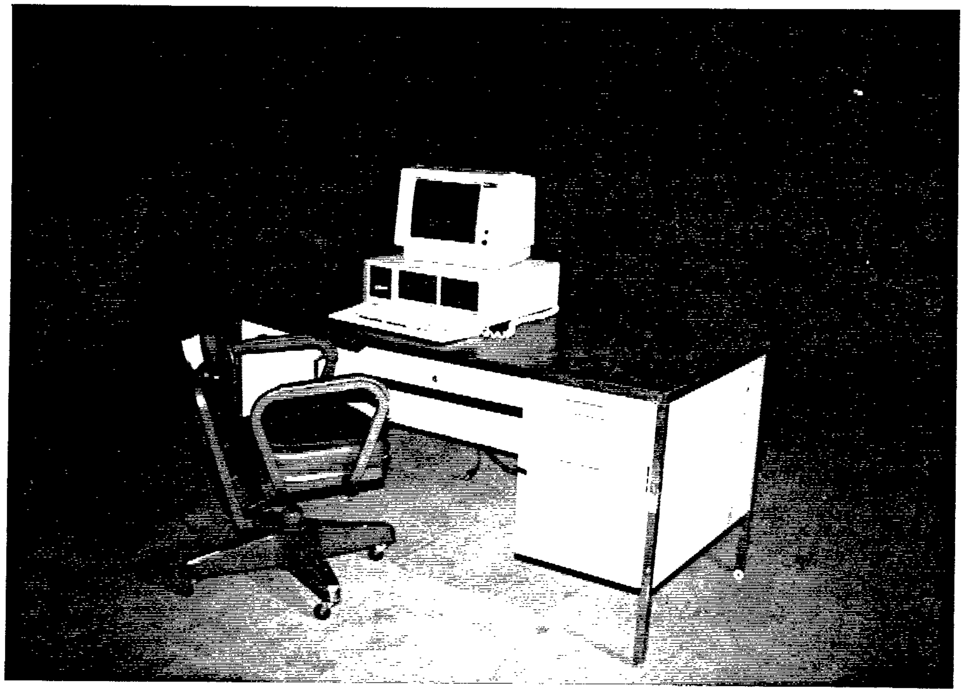


Figure 3-14. Desk, computer, monitor, and chair set up 100 ft down A-drift from the detonation of 20 lb of propylene oxide.

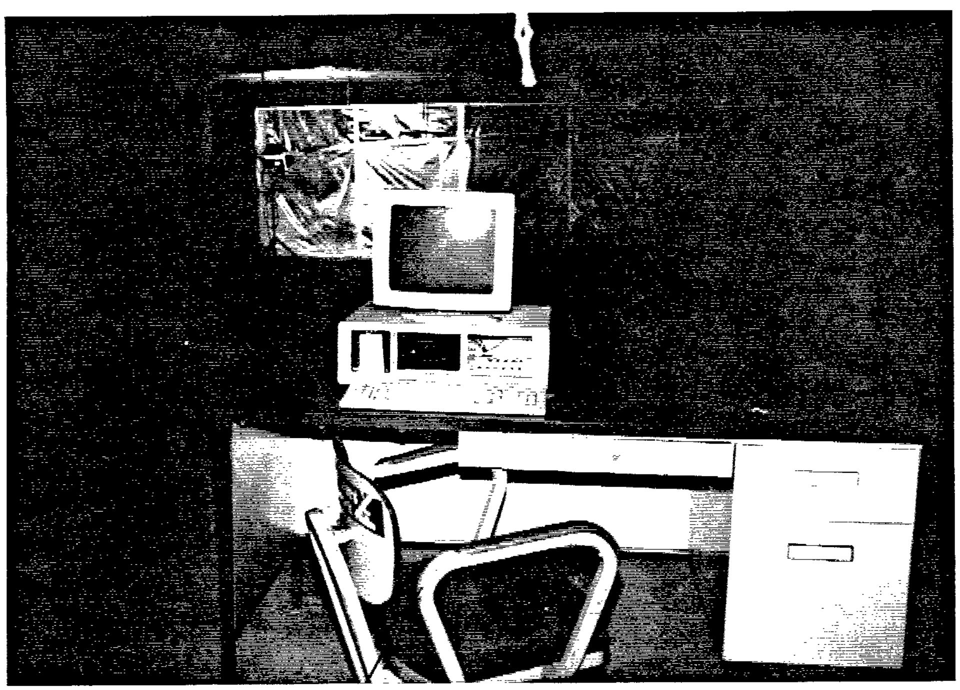


Figure 3-15. Desk, computer, monitor, and chair set up 60 ft down E-drift from the detonation of 20 lb of propylene oxide.

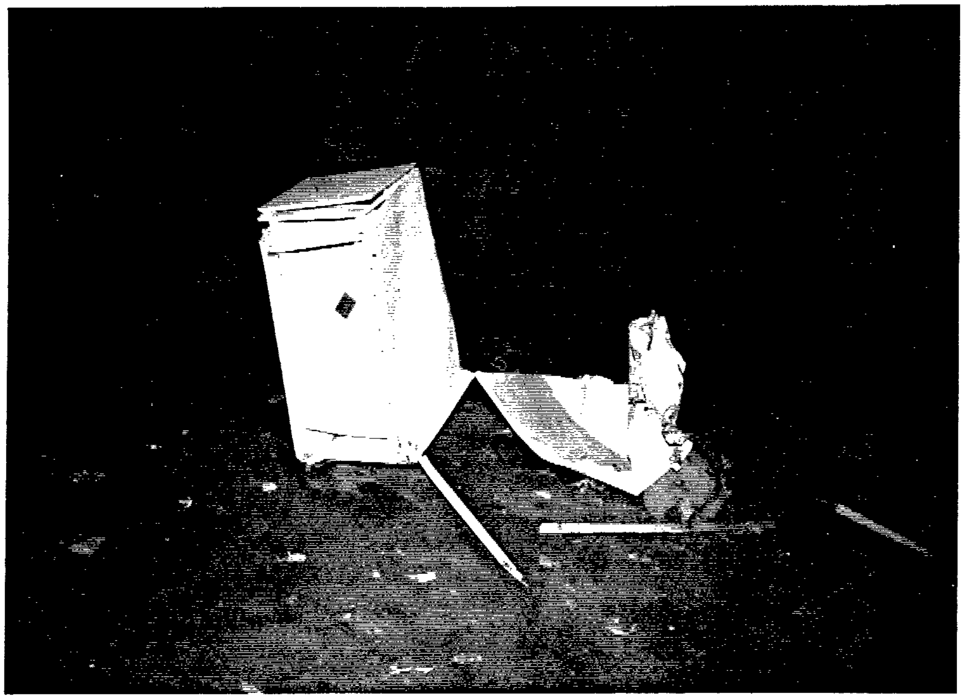


Figure 3-16. Damage to the desk located 100 ft down A-drift from the 20-lb propylene oxide detonation.

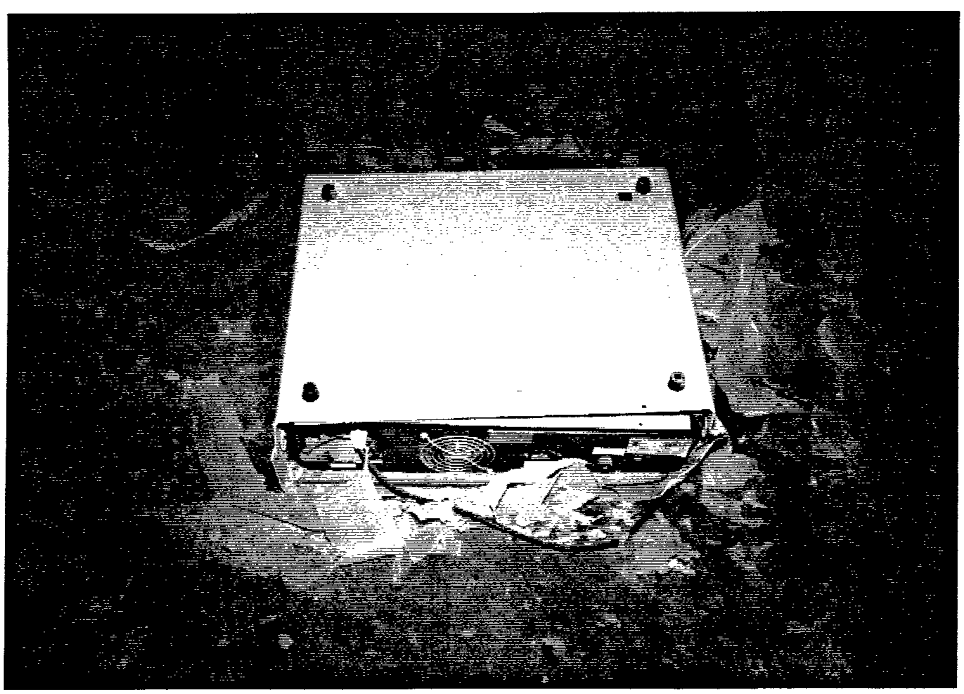


Figure 3-17. Damage to the computer located 100 ft down A-drift from the 20-lb propylene oxide detonation.

Figure 3-18. Damage to the monitor located 100 ft down A-drift from the detonation of 20 lb of propylene oxide.

Figure 3-19. Damage to the keyboard located 100 ft down A-drift from the detonation of 20 lb of propylene oxide.

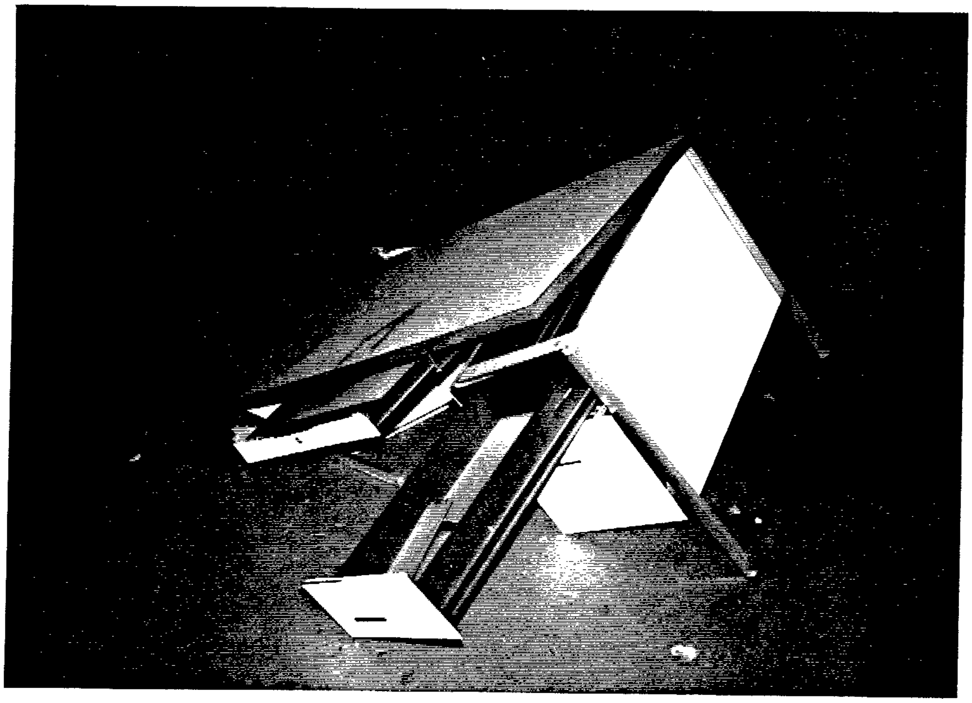


Figure 3-20. Minor damage to the desk located 200 ft down A-drift from the detonation of 20 lb of propylene oxide.

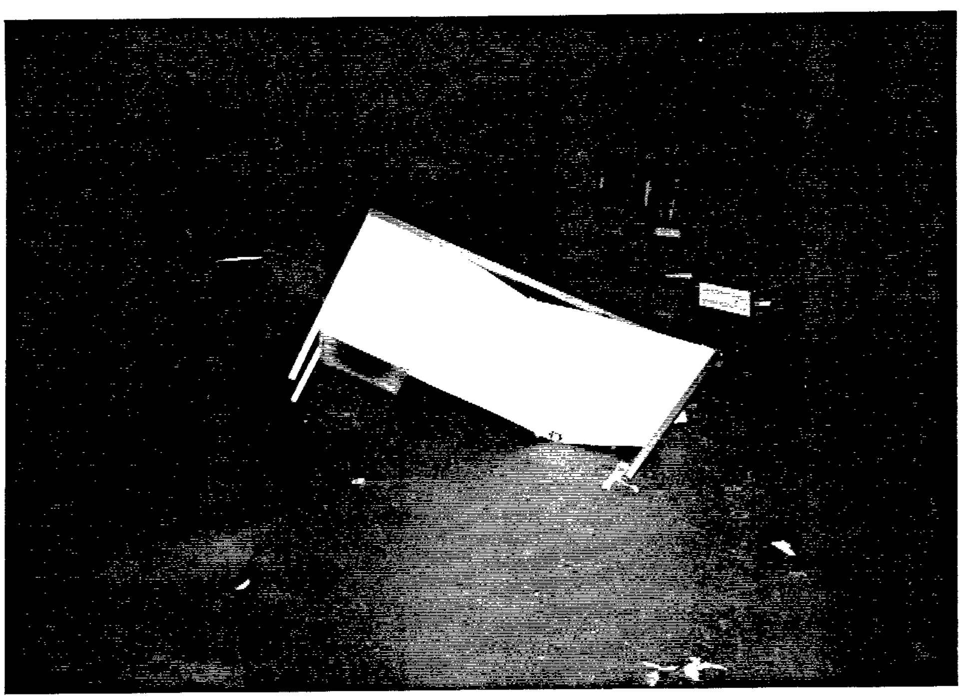


Figure 3-21. Another view of the damaged desk located 200 ft down A-drift from the detonation of 20 lb of propylene oxide.

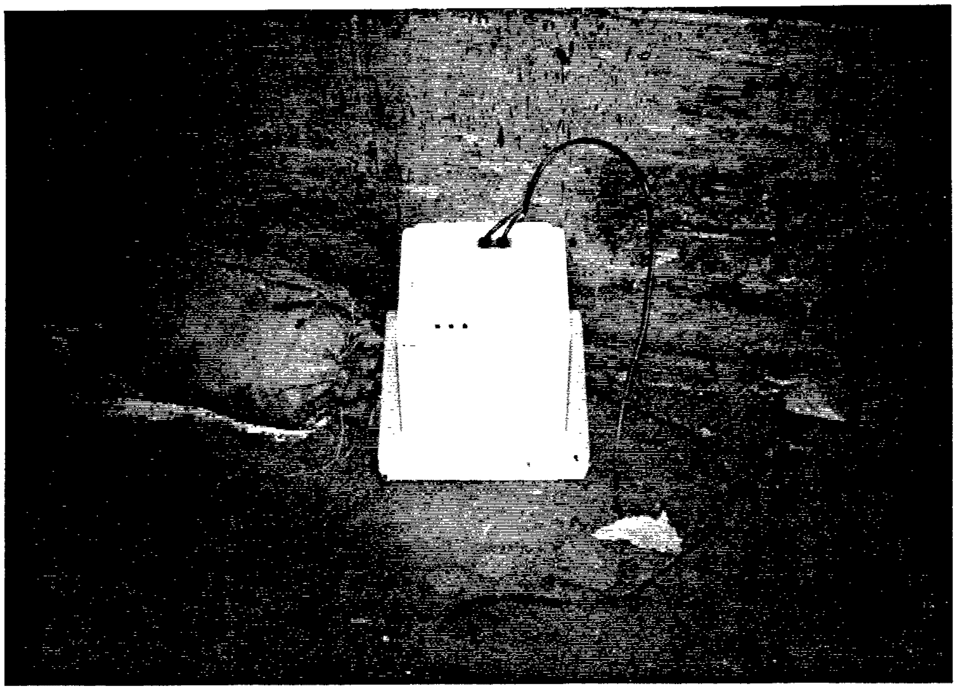


Figure 3-22. 200 ft down A-drift from the 20-lb propylene oxide detonation, the monitor was thrown to the floor but was not severly damaged.

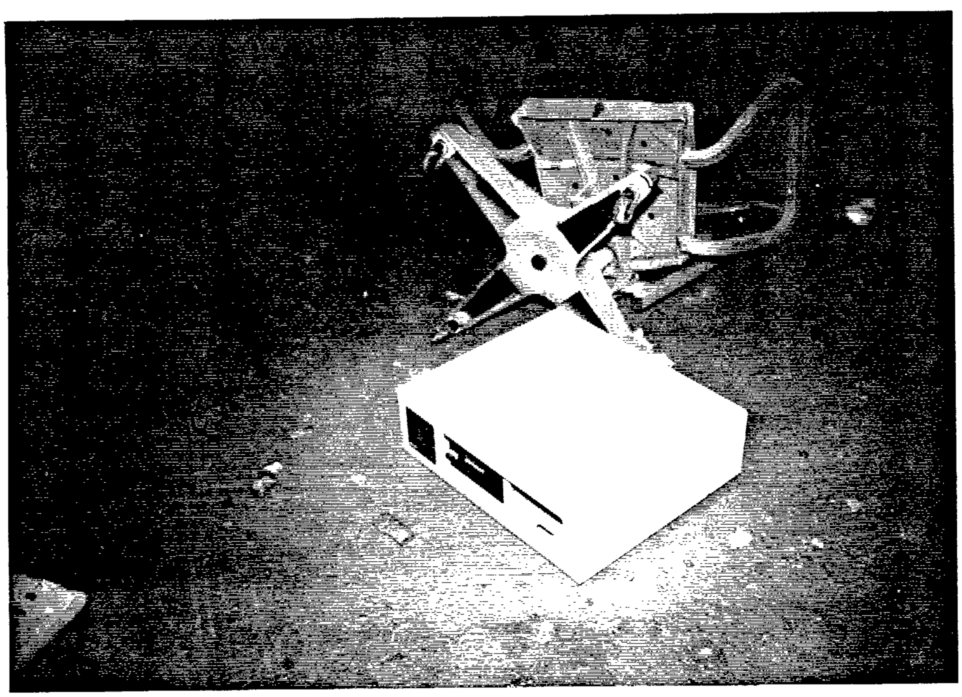


Figure 3-23. 200 ft down A-drift from the 20-lb propylene oxide detonation the computer was thrown to the floor but was not severely damaged.

Figure 3-24. Damage to the computer, monitor, desk, and chair set up 60 ft down E-drift from the 20-lb propylene oxide detonation.

Figure 3-25. Another view of the damage 60 ft down E-drift from the 20-lb propylene oxide detonation.

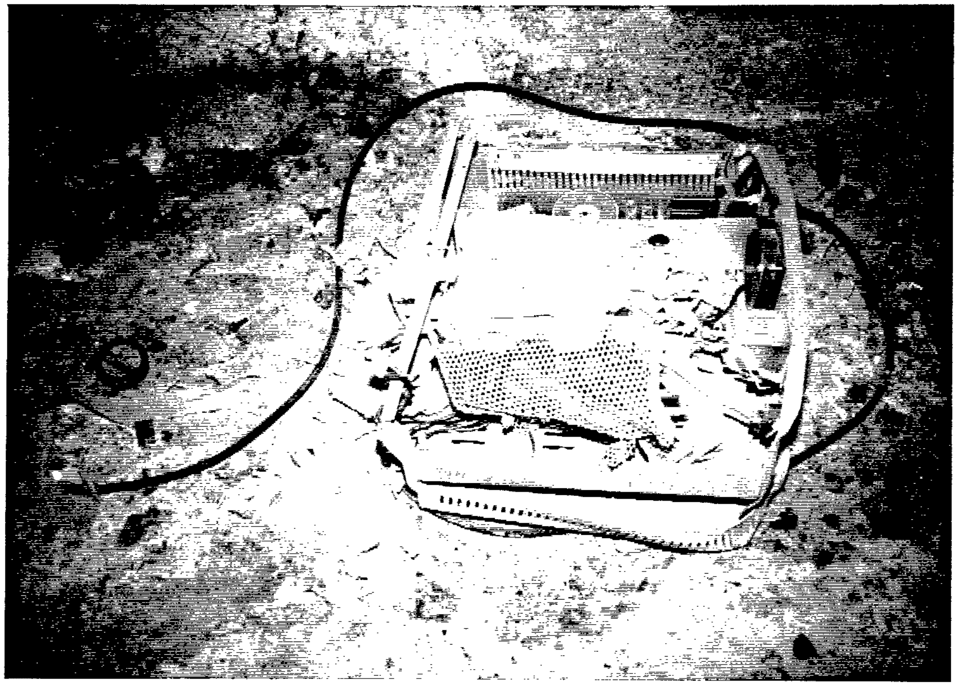


Figure 3-26. Damage to the computer located 60 ft down E-drift from the 20-lb propylene oxide detonation.

Figure 3-27. Disk drive and keyboard from the computer located 60 ft down E-drift from the 20-lb propylene oxide detonation.

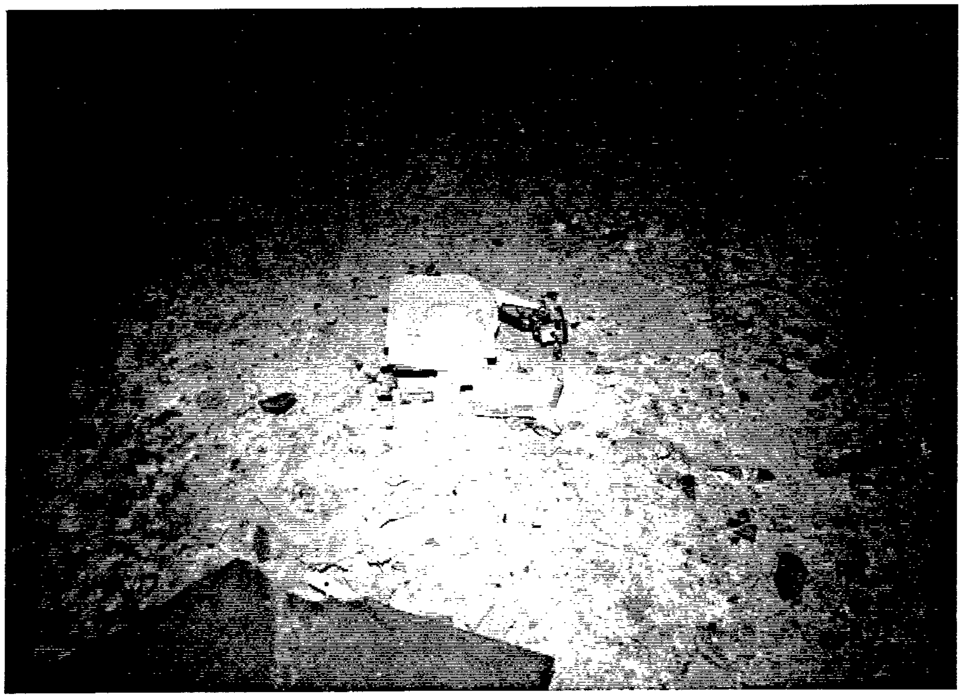


Figure 3-28. Damage to the monitor located 60 ft down E-drift from the 20-lb propylene oxide detonation.

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