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BUGGY

CLOSE-IN AIRBLAST
FROM THE
BUGGY I EVENT

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PROJECT BUGGY I

CLOSE-IN AIRBLAST FROM THE BUGGY I EVENT

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ABSTRACT

Airblast measurements from the BUGGY I nuclear row-charge cratering detonation were made at five ground-level stations to distances of about two miles, along each of four lines placed on axes of the row. No appreciable effects of terrain on airblast propagation were observed, even though terrain relief was pronounced. Peak ground-shock-induced overpressures measured perpendicular to the row were up to 3.7 times those measured off the ends. Differences were not constant because peaks attenuated with distance differently in the two directions. Ground-shock-induced peak overpressures were about equal to gas-venting peak overpressures off the ends of the row, while perpendicular to the row, ground-shock-induced peaks were decidedly larger. Peak ground-shock-induced and gas-venting overpressures were up to 3.7 and 2.8 times, respectively, those of the CABRIOLET nuclear single-charge cratering event.

FOREWORD

This document is the author's report to the Technical Director of Project BUGGY I. The findings and conclusions contained herein are those of the author and are not necessarily those of the Atomic Energy Commission. Accordingly, references to this material must cite the author.

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These measurements of the BUGGY I airblast were obtained by B. C. Holt. He was assisted in the planning and engineering by H. G. Laursen. The data were reduced by R. J. Beyatte. J. W. Long prepared the playbacks presented herein.

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CLOSE-IN AIRBLAST FROM THE BUGGY I EVENT

CHAPTER I - INTRODUCTION

1.1 Description of the BUGGY I Event

Project BUGGY was the first nuclear row-cratering detonation executed as part of the Plowshare Program for development of nuclear excavation techniques. Five nuclear explosives, each with a yield of 1.1 kt, were detonated simultaneously at 0904:00. 111 PST, 12 March 1968. The depths of burst were at 135 feet, and the spacing between explosives was 150 feet. The experiment took place on Chukar Mesa, Area 30, Nevada Test Site, in a dry, complex basalt formation. Surface ground zero coordinates of the end emplacement holes designated as U-30-A and U-30-E were:

	<u>U-30-A</u>	<u>U-30-E</u>
NTS Grid Coordinates	N 821, 828.24	N 822, 039.76
	E 586, 630.95	E 586, 069.54
LATITUDE	N 37° 0' 26.9695"	N 37° 0' 29.0784"
LONGITUDE:	W 116° 22' 11.8817"	W 116° 22' 18.7955"

The line of charges was on a bearing of N 69° 21' 05" W. Ground elevations at each hole were as follows:

	<u>HOLE U-30-A</u>	<u>-B</u>	<u>-C</u>	<u>-D</u>	<u>-E</u>
Elevation (MSL) (feet)	5208.28	5210.04	5210.52	5209.47	5208.42

The principal objectives of the experiment were to:

- (1) Determine nuclear row crater parameters through level terrain in a hard, dry rock;
- (2) Determine the fraction of radioactivity that escapes the immediate cratered area.

Apparent crater dimensions that describe the excavation are:

Apparent crater width, average (W_a)	254	feet
Apparent crater depth, maximum (D_a)	69.8	feet
Lip crest width, average (W_{al})	355	feet
Apparent crater length (L_a)	865	feet
Apparent lip height, average (H_{al}) sides	41	feet
Apparent lip height, average (H_{al}) ends	14	feet
Apparent crater volume	262,456	yd ³
Apparent lip volume	422,205	yd ³

1.2 Objectives

The objectives of the experiment were:

- To measure close-in airblast as a function of distance from a nuclear row-charge explosion in hard rock, and to compare these measurements with those from the CABRIOLET nuclear single-charge event and the DUGOUT high-explosive row-charge event.
- To establish blast suppression as a function of charge burial depth and spacing between charges, as a basis for developing a model for predicting blast from large-yield nuclear excavations.

1.3 Background

Close-in airblast from single TNT shots in hard rock (Project BUCKBOARD¹) showed little difference from that of single TNT shots in alluvial soil (Project STAGECOACH² and Project SCOOTER³). Both exhibited two waves propagated at sonic velocity in air, one due to the piston action of the ground shock at the epicenter, and the second, larger, pulse due to venting gases. Project DANNY BOY^{4, 5}, the first nuclear cratering experiment in hard rock (0.43 kt at 115 feet), gave signals in which, by contrast, the initial wave was the larger. Lack of an accurate time base on the records prevented positive identification of larger constituents of the wave. The records for Projects DUGOUT⁶ (a row of five 20-ton nitromethane charges buried 59 feet deep and spaced 45 feet apart), SULKY⁷ (a single 0.085-kt nuclear charge at 90 feet), and PALANQUIN⁸ (a single 4.3-kt nuclear charge at 280 feet) were accurately timed and provided the opportunity for positive identification of four blast-wave constituents, which were as follows:

- A ground-transmitted, ground-shock-induced pulse that is maximum at the epicenter, propagated radially from the explosion at sonic velocity in rock. Because the ground shock attenuates rapidly with distance, so does the airblast it generates. The attenuation rate of the induced air pulse is further increased because only the vertical component of ground motion generates airblast, and that component decreases rapidly with decreases

in the ratio of burial depth to distance. The direct ground-shock-induced pulse was not positively identified from arrival times on either the DUGOUT or SULKY shots because of the great spacing between the epicenter and the closest gage. However, it may have been indicated by a larger-than-expected peak overpressure at the closest gage station on each event. The pulse was recognized at the ground-zero station on the PALANQUIN event. Measurements made on the CABRIOLET⁹ event permitted identification of the wave at 0, 100, and 200 feet.

- b. A seismic-wave-induced pulse was observed from the closest to the most distant stations on the DUGOUT, SULKY, and PALANQUIN events. This pulse propagated in basalt at about 4500 ft/sec--slower than the shock velocity in rock but faster than that in air. On the PALANQUIN event, the velocity in rhyolite was about 4900 ft/sec. On CABRIOLET, the wave was observed from 800 feet and beyond. Velocity varied with distance, suggesting other paths through higher velocity media, and that the wave train was not solely induced by either surface or body waves at all stations.
- c. The air-transmitted, ground-shock-induced pulse is, at the epicenter, the same as the ground-transmitted ground-shock-induced pulse. From a given point (375 feet in the case of CABRIOLET) it propagates outward at shock velocity in air rather than at propagation velocity through the ground. For Projects CABRIOLET, PALANQUIN, SULKY, and DUGOUT, it was the dominant wave, and is presumed to have been the dominant pulse for DANNY BOY.
- d. The final pulse is that due to venting gases. On PALANQUIN, SULKY, and DUGOUT, the pulse's arrival coincided with the negative phase following the air-transmitted, ground-shock-induced pulse. (A double pulse was observed on the PALANQUIN event.) Because of this and the small amount of gas created by the nuclear explosion, the peak overpressures from the SULKY gas-venting pulse did not rise above ambient pressure. On CABRIOLET, overpressures from the gas-venting pulse were well above ambient at stations beyond 300 feet, but still were not as large as the peak from the air-transmitted, ground-shock-induced pulse. The CABRIOLET gas-venting pulse was much weaker than the ground-shock-induced pulse at stations closer than 300 feet.

In addition to the principal objectives, BUGGY I, like DUGOUT, was designed (1) to shed light on how row-charge airblast is related to single-charge airblast, (2) to discern azimuthal variations in airblast from a row charge, (3) to evaluate terrain effects, and (4) to give information on differences between airblast from nuclear row-charge craters in rock and that from high-explosive row charges in soil.¹⁰ Comparison of DUGOUT results with those from a smaller but similar row in soil¹¹ showed similarities in waveform conformation, but differences in amplitudes and times. Azimuthal variations, too, were different. There also were differences in explosive between DUGOUT and the smaller-charge work in soil, nitromethane being used on the former and TNT on the latter. As a result of measurements made on Pre-SCHOONER II¹² and on a more recent series in Albuquerque alluvium¹³, an appreciable difference in airblast from nitromethane and TNT shots is suspected.

1.4 Theory

There is no comprehensive theory of propagation of airblast from row charges.

Perpendicular to the row, analytical considerations indicate that if shock waves from n charges are acoustically superimposed, the peak overpressure from the row will be n times that from a single charge. The least overpressure one might expect, if the peak overpressure were from a single charge of the same weight as the total weight in the row, and that was buried at the same scaled burial depth as a charge in the row, would be $n^{1/3}$ times the peak overpressure from one of the charges in the row. If the total charge weight were detonated at the same actual burial depth as one of the charges in the row, the peak overpressure would appear as from a shallower scaled burial depth.

Off an end of the row, acoustic addition would not involve peaks, but waveforms, displaced by the transit time of the shock across the spacing between charges. Thus, overpressures n times those of a single charge could not be achieved. The least overpressure one might expect would occur where spacing was large, so that the transit time of the shock was equal to or larger than the positive-phase duration, in which maximum overpressure would be that of one of the charges in the row.

Experimental work¹⁰ has shown that none of these cases prevails, but that airblast is a complex function of azimuth about the row, number of charges in the row, spacing between charges, distance from the row, and the pressure-time waveform. It was also shown that the relationship with each of these factors was different for each of five blast parameters: ground-shock-induced peak overpressure, peak overpressure from venting gas, peak negative pressure, positive-phase impulse, and negative-phase impulse.

CHAPTER II - PROCEDURE

2.1 Experiment Plan

On earlier experiments where airblast from row charges was measured, it has been the practice where the ground was level, or nearly so, to locate gages along two blast lines, one perpendicular to the row and one off the end of the row. Because of the gross terrain features surrounding the BUGGY I site (see map, Figure 2.1, and photo, Figure 2.2), a blast line uninterrupted by canyons or other land forms could not be located on either side of the row or off either end of the row. To be certain of gage stations at the desired distances, as well as to check on possible perturbations of the blast wave by terrain irregularities, it was decided to use four blast lines located in opposite directions, both perpendicular to the row and off the ends. To minimize terrain effects, locations where abrupt changes in terrain occurred were avoided. Earlier work^{14, 15, 16, 17} had shown that peak overpressures measured along inclining slopes are greater than those measured along level terrain, while those measured along declining slopes are less. Thus, where terrain was not flat, an effort was made to locate stations along the nose of a ridge.

Table 2.1 lists the locations of stations along each of the four blast lines. Table 2.2 gives the expected peak overpressure at each station. As in the past, two gages were located at each station, each with a different set range. The lower range indicated in Table 2.2 represented the best pre-shot estimates of expected pressures. The higher range (higher by a factor of 5) was protection against surprises. Information was recorded in such a way that a peak overpressure 50 percent greater than that indicated could be recorded without limiting any part of the system. Experience has shown that the use of duplicate gages at a station precludes some of the problems associated with difficulties of calibrating gages at these relatively low overpressures. Where two gages were used, the less sensitive is indicated by (-1) and the more sensitive by (-2). No gages were located at or near ground zero.

2.2 Instrumentation

For all stations beyond 2500 feet on the NNE, SSW, and ESE lines, information was obtained with Schaevitz-Bytrex gages (Model HED) in which the pressure-induced force of a diaphragm against a post is interpreted as strain in the post. Information from these gages was multiplexed and telemetered to the recording trailer. Pace, P7D gages with diaphragm motion interpreted through a variable-reluctance system were used for all remaining stations. Information from Pace gages was hard-wired to the instrument trailer. All information was recorded on an Ampex LP-100 magnetic-tape recording system. There were no gage or system failures on BUGGY I, although, as will be evident from subsequent chapters, many of the less-sensitive gages presented records with a low signal-to-noise ratio. In some cases a single gage was used but was recorded at dual range, as shown in Table 2.3.

Figure 2.1. Terrain of BUGGY I Site

Figure 2. 2. Contours of BUGGY I Site

Table 2.1

STATION LOCATIONS ON BLAST LINES

<u>Station</u>	<u>Bearing & Dist. from Emp. Hole</u>	<u>North</u>	<u>East</u>	<u>Elevation</u>
500 NNE	N 20° 39' 50" E 489.96'(C)*	822,392.40	586,522.92	5192.93
4100 NNE	N 20° 38' 28" E 4078.15'(C)*	825,749.18	587,787.19	5274.43
5900 NNE	N 21° 07' 58" E 5962.08'(C)*	827,493.34	588,498.86	5422.42
8000 NNE	N 24° 48' 38" E 7762.85'(C)*	828,978.05	589,606.42	5435.05
10500 NNE	N 22° 59' 09" E 10352.88'(C)*	831,461.74	590,391.56	5478.41
500 SSW	S 20° 55' 56" W 534.58'(C)*	821,434.99	586,159.16	5185.09
1000 SSW	S 20° 38' 43" W 1001.50'(C)*	820,995.78	585,999.65	5203.42
2500 SSW	S 20° 40' 42" W 2458.80"(C)*	819,634.51	585,482.12	5278.91
6600 SSW	S 21° 50' 03" W 6598.20'(C)*	815,811.34	583,896.92	5490.98
9500 SSW	S 20° 50' 54" W 9644.74'(C)*	812,923.94	582,918.72	5810.96
500 ESE	S 69° 22' 51" E 500.23'(A)*	821,652.14	587,098.98	5178.11
1000 ESE	S 69° 22' 42" E 993.76'(A)*	821,478.36	587,560.72	5172.19
2000 ESE	S 69° 20' 42" E 1996.59'(A)*	821,124.20	588,498.57	5171.13
7000 ESE	S 66° 30' 47" E 7247.71'(A)*	818,940.72	593,275.93	5149.75
9500 ESE	S 67° 51' 46" E 9306.32'(A)*	818,322.56	595,248.31	5119.53
500 WNW	N 69° 21' 22" W 500.00'(E)*	822,215.98	585,601.80	5210.36
1000 WNW	N 69° 21' 14" W 985.01'(E)*	822,386.95	585,148.11	5202.45
2000 WNW	N 69° 21' 10" W 1977.11'(E)*	822,736.68	584,220.05	5197.30
4000 WNW	N 69° 21' 07" W 3728.60'(E)*	823,444.34	582,342.21	5207.13
8000 WNW	N 69° 21' 06" W 7583.44'(E)*	824,896.51	578,488.69	5465.35

* (C) Indicates bearing & distance from emp. hole "C"

(A) Indicates bearing & distance from emp. hole "A"

(E) Indicates bearing & distance from emp. hole "E"

Table 2.2
EXPECTED OVERPRESSURE FOR BUGGY I

	<u>Expected Pressure</u>	
	<u>High</u>	<u>Low</u>
500 NNE	5.0 psi	1.0 psi
4,100 NNE	0.60	0.15
5,900 NNE	0.45	0.09
3,000 NNE	0.30	0.07
10,500 NNE	0.25	0.05
500 SSW	5.0	1.0
1,000 SSW	2.5	0.5
2,500 SSW	1.3	0.25
7,600 SSW	0.35	0.075
9,800 SSW	0.25	0.05
500 ESE	2.25	0.45
1,000 ESE	1.2	0.22
2,000 ESE	0.5	0.12
7,000 ESE	0.15	0.03
9,500 ESE	0.12	0.022
500 WNW	2.25	0.45
1,000 WNW	1.2	0.22
2,000 WNW	0.5	0.12
4,000 WNW	0.25	0.05
7,400 WNW	0.15	0.03

Table 2.3
BUGGY INSTRUMENTATION

<u>Location</u>		<u>Type Gage</u>	<u>Cal/Psi</u>
NNE	500-1	P	5.0
	-2	P	.99
	4100-1)	S-B	.152
	-2)		
	5900-1)	S-B	.0906
	-2)		
	8000-1)	S-B	.071
	-2)		
SSW	10500-1)	S-B	.0497
	-2)		
	500-1	P	4.9
	-2	P	1.0
	1000-1	P	2.5
	-2	P	.49
	2500-1	P	1.34
ESE	-2	P	.247
	6600-1	P	.354
	-2	P	.076
	9800-1	P	.25
	-2	P	.051
	500-1	P	2.27
	-2	P	.45
WNW	1000-1	P	1.9
	-2	P	.218
	2000-1	P	.49
	-2	P	.118
	7000-1)	S-B	.0395
	-2)		
	9500-1)	S-B	.0297
	-2)		
WNW	500-1	P	2.23
	-2	P	.45
	1000-1	P	1.20
	-2	P	.218
	2000-1	P	.51
	-2	P	.117
	4000-1	P	.250
	-2	P	.050
	8000-1	P	.149
	-2	P	.0306

NOTES: Dual range was achieved at some stations by using a single S-B gage, two voltage-controlled-oscillators, and a voltage divider network. In "Type Gage" P means Pace Model P7D and S-B means Schaevitz-Bytrex Model HED.

2.3 HE Calibration Shots

Two 95-pound high-explosive charges were detonated about two weeks prior to BUGGY I (Table 2.4) with expected pressure as indicated in Table 2.5. The purpose was to provide a field check on the BUGGY I instrument system, to determine from a typical waveform whether there were terrain effects; and to get some idea of their magnitude if they did exist. The explosive charge was suspended above ground in a cloth bag. Firing times in the early and late morning were chosen.

The charges were detonated 300 feet ESE of U30E, i. e., 300 feet off the end of the axis of the BUGGY I row. Larger charges would have provided a better signal and the symmetry provided by a location at U30C would have been preferred, but both were precluded by facilities at BUGGY I ground zero.

Table 2.4

BUGGY H. E. SHOTS

<u>H. E. Shot</u>	<u>Detonation</u>	<u>Temperature (at Ground Level)</u>	<u>Wind Direction and Velocity</u>
Shot No. 1 95-pound Comp B.	Detonated at 0825 2/24/68 PST	52° F (11° C)	S., S. E., approx. 5 knots (8.4 ft/sec)
Shot No. 2 95-pound Comp B.	Detonated at 1215 2/24/68 PST	65° F (18.3° C)	E., N. E., approx. 7 knots (11.8 ft/sec)

Table 2.5

EXPECTED OVERPRESSURE FOR H.E. CALIBRATION SHOTS

	<u>Expected Pressure (psi)</u>
500 NNE	.40
4,100 NNE	.18
5,900 NNE	.09
8,000 NNE	.07
10,500 NNE	.05
500 ESE	1.7
1,000 ESE	0.5
2,000 ESE	0.2
7,000 ESE	0.05
9,500 ESE	0.04
500 SSW	.40
1,000 SSW	.18
2,500 SSW	.09
7,600 SSW	.07
9,800 SSW	.05
500 WNW	.20
1,000 WNW	.15
2,000 WNW	.10
4,000 WNW	.05
7,400 WNW	.03

CHAPTER III - TEST RESULTS

3.1 HE Calibration Shots

Summary of Results -- Results of measurements made on the two calibration shots are summarized in Tables 3.1 and 3.2. Overpressure-time records for the first calibration shot are presented in Appendix A and those for the second in Appendix B. Ordinarily, results from the more-sensitive gages (identified by "-2") were used. Measurements by the less-sensitive as well as the more-sensitive gages have been included where good records were obtained for both. In certain cases, information was not obtained with the more-sensitive gage and only the results from the less-sensitive gage have been listed. Usable information was not obtained on the first calibration shot on the NNE line at 4100, 8000, 10,000 feet, nor at 9800 feet along the SSW line. On the second calibration shot, no usable information was obtained at 4100 and 5900 feet on the NNE line.

Evaluation of Records -- Records obtained for each gage had varying amounts of noise, depending upon the signal-to-noise ratio, which in turn was a function of the ratio of the overpressure measured on a calibration shot to that expected on BUGGY I. Because the calibration shots were fired at a location 300 feet ESE, the pressures along the ESE line were more nearly those expected for BUGGY I, and the signal-to-noise ratio was larger, than on other lines. A signal of approximately 40 Hertz appeared on the records of the three closest stations along the SSW line. This occurred on both calibration shots.

On the second calibration shot, very poor records were obtained at the 8000-ft and 10,500-ft stations on the NNE line. The poor records had a superimposed low-frequency signal, for reasons that are not known. The two records for SSW 9800 on Cal 2 show a discrepancy possibly due to gage calibration differences or the use of a calibration resistor different from that recorded. Although the signal-to-noise ratio is poorer, the record for SSW 9000-1 is considered the more reliable.

3.2 BUGGY I

Summary of Results -- Measurements made on the BUGGY I event are summarized in Table 3.3. Overpressure-time records for the event are reproduced in Appendix C. In most cases, good records were obtained for gages of both high and low sensitivity.

Evaluation of records -- All records obtained were especially good with the exceptions noted in the following. Both gages at the WNW 2000 station gave records which, instead of being pressure-time waveforms, as expected, were actually derivatives of overpressure-time. This would have occurred if the gage canister bleed-plug had been omitted on BUGGY I but not on the calibration shots, since the same

TABLE 3.1

SUMMARY OF RESULTS

Buggy Cal. Shot #1 8:25 AM PST 2-24-68

Station	Range (feet)	Arrival Time (sec)	Peak Positive Overpressure (psi)	Time Of Peak (sec)	Cross- over Time (sec)	Peak Negative Pressure (psi)	Time of Peak (sec)	Positive Impulse (psi-sec)
NNE 500-2	775	0.686	0.056 ± 0.01	0.697	0.735	0.03 ± 0.01	0.074	0.0020
NNE 4100-1	4121	3.703	0.015 ± 0.002	3.704	3.710	0.0032	3.74	
NNE 5900-1	5985	5.390	0.0115 ± .0015	5.393	5.418	0.0045 ± .0015	5.45	0.00015
NNE 5900-2	5985	5.390	0.0115 ± .001	5.393	5.418	0.0045 ± .001	5.45	
NNE 8000	7740							
NNE 10,500	10342							
SSW 500-2	806	0.715	0.21 ± .04	0.715	0.752	0.06 ± 0.04	0.78	0.00312
SSW 1000-2	1166	1.039	0.158 ± .015	1.041	1.074	0.040 ± .015	1.105	0.00190
SSW 2500-2	2530	2.263	0.057 ± .01	2.266	2.298	0.018 ± .008	2.330	0.00079
SSW 6600-1	6636	5.946	0.0148	5.954	5.980	0.0062		
SSW 660-2	6636	5.946	0.0172	5.954	5.980	0.008	6.015	0.00028
SSW 9800	9662							
ESE 500-1	200	0.162	0.920	0.166	0.189	0.025	0.210	
ESE 500-2	200	0.162	0.95	0.166	0.189	0.275	0.210	0.0102
ESE 1000-1	694	0.603	0.335	0.606	0.635	0.08	0.658	
ESE 1000-2	694	0.603	0.33	0.606	0.635	0.08	0.658	0.00326
ESE 2000-2	1697	1.510	0.077	1.513	1.545	0.032	1.585	0.00128
ESE 7000-1	6948	6.263	0.0136	6.267	6.306	0.0052	6.347	0.00021
ESE 7000-2	6948	6.663	0.0136	6.267	6.306	0.0048	6.347	
ESE 9500-1	9306	8.137	0.00625 ± .00025	8.140	8.185	0.0040 ± .00025	8.222	0.00015
WNW 500-1	1400	1.244	0.082 ± .01	1.250	1.281	0.047 ± .01	1.314	
WNW 500-2	1400	1.244	0.0825 ± .0075	1.250	1.281	0.033 ± .0090	1.314	0.00118
WNW 1000-1	1885	1.684	0.049	1.685	1.717	0.021	1.751	
WNW 1000-2	1885	1.684	0.048	1.686	1.717	0.017	1.751	0.00080
WNW 2000-2	2877	2.576	0.0317	2.580	2.608	0.018	2.640	0.00049
WNW 4000-2	4629	4.380	0.015	4.388	4.423	0.0064	4.449	0.00034
WNW 8000-2	8483	8.090	0.0106	8.103	8.140	0.0056	8.169	0.00025

TABLE 3.2

SUMMARY OF RESULTS

Buggy Cal. Shot #2 12:15 PM PST 2-24-68

Station	Range (feet)	Arrival Time (sec)	Peak Positive Overpressure (psi)	Time of Peak (sec)	Cross- over Time (sec)	Peak Negative Pressure (psi)	Time of Peak (sec)	Positive Impulse (psi-sec)
NNE 500-2	775	.695	.074 ± .008	.710	.735	0.034 ± 0.008	.760	.0022
NNE 4100	4121							
NNE 5900	5985							
NNE 8000-2	7740	7.140	.0183 ± .002	7.147	7.2185	.00370 ± .002	7.33	.00027 ± .00010
NNE 10500-1	10342	9.259	.0030 ± .0003	9.2665	9.325	.00100 ± .0003	9.34	.00006
SSW 500-2	806	.713	.198 ± .02	.72	.749	.055 ± .02	.778	.00252
SSW 1000-2	1166	1.037	.140 ± .01	1.04	1.07	.032 ± .008	1.099	.00169
SSW 2500-2	2530	2.253	.040 ± .005	2.256	2.291	.014 ± .005	2.323	.00069
SSW 6600-1	6636	5.925	.007 ± .001	5.930	5.968	.0039 ± .001	6.005	.00014
SSW 9800-2	9662	8.645	.0011	8.672	8.698			.00003
ESE 500 ⁻¹ ₋₂	200	.170	1.21 ± .02	1.72	.191	.287 ± .02	.201	.01091
		.170	1.08	1.72	.191	.27	.2005	.01013
ESE 1000-2	694	.605	.304	.606	.6305	.0825	.663	.00267
ESE 2000 ⁻² ₋₁	1697	1.499	.064	1.505	1.532	.0275	1.566	.00110
		1.499	.0614 ± .005	1.502	1.536	.026 ± .005	1.566	.00102
ESE 7000 ⁻² ₋₁	6948	6.17	.00568	6.188	6.217	.00220	6.27	.00014
		6.177	.00565	6.188	6.218	.00221	6.256	.00014
ESE 9500-1	9306	8.02	.0026 ± .0003	8.025	8.072	.00190 ± .0003	8.105	.00007
WNW 500-2	1400	1.25	.079 ± .005	1.251	1.281	.020 ± .005	1.319	.00103
WNW 1000-2	1885	1.680	.050	1.684	1.713	.0197	1.756	.00070
WNW 2000-2	2877	2.567	.022	2.578	2.604	.0132	2.645	.00044
WNW 4000-2	4629	4.369	.017	4.378	4.4065	.008	4.448	.00035
WNW 8000 ⁻¹ ₋₂	8483	8.04	.011 ± .001	8.049	8.075	.00657 ± .001	8.116	.00022
		8.04	.014 ± .001	8.0515	8.075	.0100 ± .001	8.121	.00030

TABLE 3.3
SUMMARY OF RESULTS - BUGGY I

Station	Range (feet)	Arrival Time (sec)	First Positive Peak Overpressure (psi)	Time of First Peak (sec)	Second Positive Peak Overpressure (psi)	Time of Second Peak (sec)	Crossover Time (sec)	Negative Peak Pressure (psi)	Time of Negative Peak (sec)	Crossover Time (sec)	Positive Impulse (psi-sec)	Negative Impulse (psi-sec)
NNE 500-1	490	0.078, ^a 0.410	0.2240	0.460	0.0860	1.732	2.020	0.0710	2.746	---	0.0825 ^b	---
NNE 500-2		0.078, ^a 0.410	0.2050	0.462	0.0700	1.660	1.998	0.0750	2.800	4.300	0.0720	0.1030
NNE 4100-1	4078	3.312	0.0395	3.676	0.0200	4.846	5.148	0.0175	5.928	7.480	0.0170	0.0232
NNE 4100-2		3.310	0.0382	3.676	0.0215	4.778	5.182	0.0178	5.714	7.370	0.0164	0.0227
NNE 5900-1	5960	5.156	0.0233	5.368	0.0138	6.550	6.870	0.0095	8.210	9.340	0.00895	0.0155
NNE 5900-2		5.172	0.0225	5.372	0.0130	6.576	6.850	0.0100	8.064	9.340	0.0075	0.0173
NNE 8000-1	7760	6.858	0.0145	6.990	0.0082	8.268	8.644	0.0088	9.398	10.700	0.0087	0.0090
NNE 8000-2		6.898	0.0145	6.984	0.0080	8.196	8.642	0.0088	9.312	10.750	0.0080	0.0085
NNE 10,500-1 ^c	10350	9.110	0.006	9.322	0.0033	10.540	10.918	0.0024	11.614	13.390	0.0031	0.0033
NNE 10,500-2 ^e		9.110	0.0135	9.324	0.0078	10.522	10.920	0.005	11.664	13.200	0.0068	0.0074
SSW 500-1	535	0.114, ^a (?)	0.1800	0.542	0.1170	1.516	2.450	0.0800	3.218	---	0.1115	---
SSW 500-2		0.162, ^a 0.412	0.2150	0.570	0.1050	1.542	2.344	0.0920	2.874	4.384	0.1270	0.0125
SSW 1000-1	1002	0.860	0.1610	0.968	0.075	1.940	2.720	0.0060	3.220	---	0.0790	---
SSW 1000-2		0.870	0.1610	0.968	0.0740	1.964	2.710	0.0550	3.324	---	0.0700	---
SSW 2500-1	2459	2.078	0.0640	2.290	0.0260	3.284	4.000	0.0240	4.392	---	0.0320	---
SSW 2500-2 ^e		2.106	0.0346	2.312	0.014	3.282	4.100	---	---	---	0.0170	---
SSW 6600-1	6598	5.926	0.0136	6.146	0.00850	7.162	7.815	0.0061	8.834	10.240	0.0085	0.0095
SSW 6600-2		5.958	0.0168	6.152	0.0098	7.162	7.900	0.0070 ^b	8.742	10.100	0.00965	0.0109
SSW 9800-1	9645	8.868	0.0048 ^b	9.068	0.0025 ^b	10.358	11.000	0.0034	11.668	13.100	0.0046	0.0054
SSW 9800-2 ^e		8.870	0.0065	9.054	0.0055	10.350	11.100	0.0055	12.100	13.100	0.0070	0.0088
ESE 500-1	500	0.284	0.0760	0.600	0.0690	1.790	2.150	0.0585	3.340	---	0.0685	---
ESE 500-2		0.248	0.0630	0.616	0.0640	1.782	2.270	0.0540	3.370	---	0.0555	---
ESE 1000-1	994	0.836	0.0390	1.056	0.0390	2.256	2.800	0.0360	3.560	---	0.0420 ^b	---
ESE 1000-2		0.710	0.0500	1.056	0.0520	2.256	2.710	0.0400	3.700	---	0.0410	---
ESE 2000-1	1997	1.774	0.0267	1.974	0.0267	3.158	3.800	---	---	---	0.0270	---
ESE 2000-2		1.774	0.0265	1.976	0.0265	3.126	3.790	---	---	---	0.0258	---
ESE 7000-1	7249	6.384	0.0088	6.898	0.0100	7.982	8.548	0.0072	9.256	11.000	0.0100	0.0114
ESE 7000-2		6.444	0.0093	6.878	0.0102	7.958	8.548	0.0070	9.252	11.070	0.0102	0.0117
ESE 9500-1	9306	8.336	0.0067	9.040	0.0055	9.818	10.560	0.0070	11.162	12.880	0.0076	0.0101
ESE 9500-2		8.414	0.0063	9.020	0.0055	9.802	10.454	0.0062	11.274	12.960	0.0074	0.0093
WNW 500-1	500	0.384	0.080	0.460	0.050	1.862	2.054	0.055	2.510	3.400	0.018	0.0365
WNW 500-2 ^e		0.384	0.043	0.474	0.0225	1.870	2.102	0.030	2.510	3.970	Lost	0.025
WNW 1000-1	985	0.838	0.044	0.954	0.048	2.290	2.708	0.045	3.442	5.244	0.0455	0.065
WNW 1000-2		0.832	0.0390	1.036	0.0410	2.350	2.744	0.0340	3.566	5.234	0.0450	0.069
WNW 2000-1	1977	^d		2.205								
WNW 2000-2		1.671 ^d				3.251						
WNW 4000-1	3729	3.470	0.0177	3.998	0.0167	5.008	5.452	0.0140	6.034	7.720	0.0169	0.0191
WNW 4000-2		3.420	0.0165	3.998	0.0153	5.022	5.470	0.0122	6.136	7.680	0.0165	0.0195
WNW 8000-1	7583	7.254	0.0090	7.736	0.0095	8.754	9.244	0.0075	9.814	11.480	0.0091	0.0101
WNW 8000-2		7.254	0.0091	7.728	0.0088	8.748	9.260	0.0075	9.824	11.394	0.0091	0.0101

^a Direct ground shock

^b Not an accurate value, see pressure waveform

^c Based on estimated calibration

^d Records obtained are derivatives of pressure. Integration provides approximation of waveform but without valid scale

^e Values indicate a doubtful calibration

gages were used at WNW 2000 for both the calibration shots and the BUGGY I event. An example of first (overpressure-time) and second (impulse-time) integrations of the derivative is given in Appendix C for WNW 2000-2, together with the original records for both gages. The first and second integrations are useful only for comparison of waveform, because no valid calibration of vertical scale can be accomplished.

Transient spikes with a recovery time of about 400 milliseconds were observed on NNE 500-1, ESE 1000-2, and WNW 500-2. The transients occurred at different times and, while there may have been a common cause, the cause was not a common event. A good trace was obtained for NNE 10,500-1, but the calibration step fell outside the transmission frequency band and hence provided no accurate amplitude scale. An amplitude scale was inferred from the scale of NNE 10,500-1 calibration and from the fact that the calibration steps at the two gages were intended to be different by a factor of 5. Four gages gave evidence of amplitude scale errors as follows:

NNE 10,500-2	High by	2.2-2.5 times
SSW 2500-2	Low by	0.5 times
SSW 9500-2	High by	1.5-1.6 times
WNW 500-2	Low by	0.45-0.55 times

Gages in each case were the same as used for the calibration shots. Comparison shows both gages in agreement on the calibration shots in the cases of SSW 2500 and WNW 500. For SSW 9500 the two gages were different by about the amount shown above. No comparison could be made for NNE 10,500 because of the very small signal. These errors could have resulted from lack of careful calibration of the gage or possibly from use of a calibration resistor different from the one recorded. Gages other than at WNW 500-2 had been disassembled before these possible errors were discovered. On WNW 500-2, the correct resistor had been used, and it is presumed that equal care was used with other gages.

The records from Station WNW 500 show a trace with a strong negative pressure between ground-shock-induced and gas-venting peak overpressures. At other stations, pressures merely approach ambient at that time. Other than the transient spike on WNW 500-2, the records appear credible and the difference between the waveform at WNW 500 and those at other stations seems to be phenomenological rather than a result of inaccurate measurement.

CHAPTER IV - DISCUSSION

4.1 HE Calibration Shots

Waveforms -- Shock waveforms from the two calibration shots were typical, with a rapid rise at the shock front followed by a gradual decay and a characteristic negative phase. The shock front taxes the frequency response of the gages, which are normally used for buried explosions, where the rise times are slower than for above-surface bursts. Previous gage checks have shown up to a 10 percent variation in measurement of peak overpressure from similar shock waves.

All the waveforms were characteristic except that on both shots, the records from gages at the ESE 7000 and 9500-foot stations show a wave train in which four separate peaks can be identified with a period of about 0.17 second. This would indicate a path length of about 190 feet, based on an average velocity of about 1115 ft/sec. One possible explanation for the wave train relates to the difference in path directly across 40-Mile Canyon as compared with the distance down into the canyon and up the opposite slope. This difference is about 225 feet, which is close to the difference in path length for the signals. This would account for the first of the signals but not for the subsequent reverberations. The far side of 40-Mile Canyon is terraced, and reflections from the terraces offer another possible explanation. Neither hypothesis is especially satisfying when one notes that the SSW line crossed a similar canyon without producing a wave train in records obtained from the far side of the canyon. Possibly, a similar effect was observed (only on Cal Shot 2) on records of two distant stations along the NNE line, as evidenced by a wave train with a period of about 0.4 second. This period is too long to relate to canyon dimensions, and the nature of the wave train suggests wind or system noise.

Arrival Time -- Ambient temperatures for the calibration shots indicate ambient sound velocity of 1110 ft/sec and 1124 ft/sec for Shots 1 and 2, respectively. Observed velocities between GZ and gage stations (Table 4.1) show considerable variation except for the SSW line. Average velocities for the two shots show little difference in spite of the difference in ambient sound speeds. The greatest velocity differences between the two shots are seen on the ESE line. Higher-than-ambient velocities for that line and lower-than-ambient velocities for the WNW line suggest a wind component along the common axis of those two lines of about 17 ft/sec for Shot 1, and 22 to 29 ft/sec for Shot 2. Thus, the effective wind velocity appears to have been about twice that estimated at the surface, and quite different in direction from that observed at the surface.

Impulse -- Impulse is examined first because it is a better parameter with which to determine both the quality of the records and evidence of inconsistency in gage calibration. Impulse averages out the effects of electrical noise in a channel where that noise has a frequency high enough so that several cycles are contained within the positive phase. If a gage has poor frequency-response characteristics,

TABLE 4.1
Shock Propagation Velocities

Station	RANGE		Cal 1 VELOCITY		Cal 2 VELOCITY		Elevation	Terrain Slope	Remarks
	GZ to Station	Between Stations	GZ to Station	Between Stations	GZ to Station	Between Stations			
NNE 500	775		1130		1115		5193
NNE 4100	4121	3346	1113	1109			5274		Canyon 500' deep
NNE 5900	5985	1864	1110	1105		1081	5422		Elevation increase
NNE 8000	7740	1755			1084		5435		Canyon 130' deep
NNE 10,500	10342	2602			1117	1231	5478		Shallow canyon 60' deep
SSW 500	806		1127		1130		5185
SSW 1000	1166	360	1122	1111	1111		5203		Shallow Canyon 20' deep
SSW 2500	2530	1364	1118	1114	1122		5279		Incline
SSW 6600	6636	4106	1116	1115	1118		5491		Canyon 800' deep
SSW 9800	9662	3026			1113		5811		Canyon 150' deep
ESE 500	200		1235		1176		5178		
ESE 1000	694	494	1151	1120	1136		5172		Decline
ESE 2000	1697	1003	1124	1106	1122		5171		Decline
ESE 7000	6948	5251	1109	1105	1122-4		5150		40-Mile Canyon 850' deep
ESE 9500	9306	2358	1144	1258	1275-79		5120		Canyon 200' deep
WNW 500	1400		1125		1120		5210		
WNW 1000	1885	485	1119	1102	1128		5202		Level
WNW 2000	2877	992	1117	1112	1118		5197		Level
WNW 4000	4629	1752	1057	971	972		5207		Level
WNW 8000	8483	3854	1049	1039	1050		5465		Reentrant Canyon

there will be some variance in peak overpressure measurements, whereas the effect on impulse is usually quite small. If a gage has not been properly calibrated, it will show positive and negative peak pressures and impulses that differ by corresponding ratios from other measurements made along the same blast line.

No clear evidence of gage calibration inconsistencies was demonstrated, with the possible exception of NNE 7740. No gage adjustments were made between the first and second calibration shots. On the first calibration shot, impulses along the ESE and WNW lines agree quite well (Figure 4. 1). Impulses along the NNE and WNW were consistently lower. The impulse along the WNW line shows a possible terrain effect which is discussed below.

On the second calibration shot, impulses along the WNW line show the same evidence of possible terrain effects (Figure 4. 2). Impulses on all the lines are in agreement at closer distances, but differences increase at the greater ranges.

The principle difference between impulses measured on the two shots is the increased rate of attenuation with distance observed on the second calibration shot, probably due to increased temperature gradient resulting from ground warming between 8:25 a. m. and 12:15 p. m.

Only on the WNW line was there an effect which could be interpreted as arising from terrain differences. On all other lines such terrain effects as may have existed were small compared to variation in measurements from one gage to another. This point is made clearer in the next section, where terrain profile has been added to Figures 4. 3 to 4. 6.

Positive and Negative Peak Pressures -- The most obvious effect observable from Figures 4. 3 to 4. 6 is the effect of temperature gradient on peak pressure attenuation with distance because of changes in ambient conditions between times of the two shots.

On the ESE line there were no clearly defined effects of terrain on peak pressures, although at the greater distances the signals from Shot 2 were weaker than those from Shot 1 because of increased temperature gradient. This was unexpected, inasmuch as the ESE line crossed Fortymile Canyon, and terrain effects, if any, should have been more pronounced than on other lines. On the WNW line the peaks agree reasonably well for the two shots. Here some terrain effect is indicated by lower attenuation rates at greater distances. As in the case of impulse, this is attributed to convergence of the propagation into an inclined re-entrant canyon.

Peak positive pressures for both shots on the SSW line agree well with those on the ESE line, but peak negative pressures do not agree quite so well. Both positive and negative peaks for the NNE 500-foot station are low with respect to all other measurements for both shots; otherwise, agreement is good. Since positive-phase impulse agrees well with other measurements at the same distance, a gage calibration error is not indicated. A gage with a poor frequency response is a possibility that is strengthened by the fact that the positive peak is suppressed more than the negative. The same gage was used for the BUGGY I event.

Evaluation of Calibration Shots -- The calibration shots were useful in several respects. First, they indicated rates of attenuation with distance, and showed that

Figure 4.1 Positive-phase impulse vs distance for Cal 1

Figure 4.2 Positive-phase impulse vs distance for Cal 2

Figure 4.3 Peak pressure and impulse for Cal 1 and Cal 2 along the NNE blast line

Figure 4.4 Peak pressure and impulse for Cal 1 and Cal 2 along SSW blast line

Figure 4.5 Peak pressure and impulse for Cal 1 and Cal 2 along ESE blast line

Figure 4.6 Peak pressure and impulse for Cal 1 and Cal 2 along WNW blast line

these rates were influenced by changes in ambient conditions from the time of one shot to the time of the next. They also showed that rates of attenuation on all but the WNW line, particularly at the larger distances, were significantly greater than the approximately $1/R$ which has been found on past experiments. Second, the shots showed that the principal terrain effects were two: a relatively late reverberation observed on the east side of 40-Mile Canyon, and possibly at the far end of the NNE line, and a decrease in rate of attenuation on the WNW line where the terrain increased in elevation and pressure pulses converged in a reentrant canyon. Third, the shots revealed that the gage at NNE 500-2 had poor frequency-response characteristics. Fourth, they showed that, except for SSW 9800-2, any calibration inconsistencies were small enough to be obscured by the relatively small signal-to-noise ratio observed at many of the stations.

4.2 BUGGY I

Overpressure Off the Ends of the Row -- Peak ground-shock-induced overpressures off opposite ends of the row have about the same values, and attenuate at almost the same rate (Figure 4.7). Agreement would be expected for the first 2000 feet where ground was essentially level and relatively smooth. From 3750 feet to the last station on the WNW line the terrain inclines 260 feet; however, differences in attenuation rates between WNW and ESE observed on the calibration shots were not seen in the BUGGY I results.

All stations on the ESE line are at about the same elevation, but between the third station (2000 ft) and the fourth station (7000 ft), the line crosses 850-ft deep Fortymile Canyon. The overpressure-distance relationships illustrated in Figure 4.7 show no terrain effects along these two lines. The wave-train with a period of 0.17 second seen on the calibration shots was not seen on BUGGY I, possibly because it was obscured by a positive phase of over two seconds duration.

Gas-venting peak overpressures are essentially equal to ground-shock-induced peaks and exhibit a similar rate of attenuation with distance over most of the range (Figure 4.8). The slope between the last two stations on the WNW line is about 4 degrees. Model experiments with a 5.7-degree slope show a 20 percent increase on the forward slope.¹⁷ There is little, if any, increase for the BUGGY I blast wave for either gas-venting or ground-shock-induced peak overpressures. The gas-venting pulses off the ends exhibit a single peak similar to, but without the sharp rise of, a wave from a single-charge above-ground explosion; this suggests that major venting occurred from a single-source location.

The last station on the ESE line exhibits an appreciably lower overpressure than attenuation with distance from the closer stations would indicate. Examination of the record at 7250 ft shows the gas-venting peak larger (by a small amount) than the ground-shock-induced peak, while at 9300 feet the reverse is true. The reason for the change is not obvious. With this one exception, ground-shock-induced and gas-venting peak overpressures were about the same off opposite ends of the BUGGY I row.

Impulse Off the Ends of the Row -- With one notable exception, positive-phase impulses (Figure 4.9) off opposite ends of the row constitute a continuous trend with

Figure 4.7 Ground-shock-induced overpressure vs distance off ends of BUGGY I row

Figure 4.8 Gas-venting peak overpressure vs distance off ends of BUGGY I row

distance. The exception is WNW 500-1, which shows a pronounced negative excursion between the ground-shock-induced and gas-venting peaks. Since positive impulse was measured continuously from arrival to the crossover following the gas-venting pulse, the negative excursion reduces this impulse appreciably.

Negative-phase impulse (Figure 4. 10) for the same station is low also, but is without a logical explanation.

Overpressure Perpendicular to the Row -- Peak ground-shock-induced overpressures perpendicular to the BUGGY I row (Figure 4. 11) along the closer portions of the NNE line attenuated with distance at about the same rate as the same peaks off the ends of the row. Greater rates of attenuation were observed at the greater distances along both the NNE and SSW blast lines. Peaks which were about equal at 500 ft on the two lines became larger along the NNE line at 4100 ft and beyond.

Gas-venting peak overpressures perpendicular to the row exhibit an attenuation pattern almost identical to that of the ground-shock-induced peak overpressures (Figure 4. 12). At 500 ft, peaks on the NNE line were less than on the SSW line, but by the next NNE station at 4100 ft, peaks were greater than on the SSW line and remained so throughout the distances at which measurements were made.

Impulse Perpendicular to Row -- At 500 ft, positive-phase impulse (Figure 4. 13) on the NNE line was only 0.65 times that on the SSW line, but at all other stations, impulses were about equal. Differences between positive- and negative-phase impulses (Figure 4. 14) were not large.

Comparison of Airblast Perpendicular to Row and Off the End -- At the closest stations (500 ft), peak ground-shock-induced overpressures perpendicular to the row averaged 2.8 times those off the ends. At 1000 ft the ratio increased to 3.7, declining thereafter to about 2.5 at 2500 ft, 2 at 6000 ft, and approaching 1 at the most distant stations. The decrease in ratio is caused, of course, by the lesser rate of attenuation with distance off the ends of the row.

Gas-venting peak overpressures perpendicular to the row average 1.5 times those off the ends of the row at 500 ft. By about 6000 ft, average values are about equal. At distances greater than 6000 ft, peaks perpendicular to the row have attenuated much more rapidly than off the ends so that peak overpressures perpendicular to the row are actually lower than off the ends.

Positive impulses off the two ends of the row were equal and at 500 ft were 0.9 times and 0.5 times those of the ESE and WNW perpendicular lines, respectively. Because of greater attenuation on the perpendicular than off the ends, positive-phase impulses converge, becoming equal in all four directions at about 4000 ft. Impulses are lower perpendicular to the row than off the end at greater distances.

Negative-impulse data are too sparse to permit comparisons. In general, values perpendicular to the row are close to those measured off the ends.

Comparison of Airblast from BUGGY I and Other Row Charges -- Airblast measurements have been made on four high-explosive row-charge shots, each consisting of five charges. Table 4. 2 summarizes the results from these shots and

Figure 4.9 Positive impulse vs distance off ends of BUGGY I row

Figure 4.10 Negative impulse vs distance off ends of BUGGY I row

Figure 4.11 Ground-shock-induced peak overpressure vs distance perpendicular to BUGGY I row

Figure 4.12 Gas-venting peak overpressure vs distance perpendicular to BUGGY I row

Figure 4.13 Positive impulse vs distance perpendicular to BUGGY I row

Figure 4.14 Negative impulse vs distance perpendicular to BUGGY I row

TABLE 4.2

COMPARISON OF AIR BLAST FROM ROW CHARGES AND SINGLE CHARGES

	BUGGY I	DUGOUT	211-16	211-44	PRE-CAPSA 5
Medium	Basalt	Basalt	Playa	Playa	Alluvium
Explosive	Nuclear	Nitromethane	TNT	TNT	TNT
Yield or Charge Weight (W)	1.1 kt	20 tons	64 lbs	64 lbs	256 lbs
Charge Burial Depth DOB(ft)	135	59	6	6.9	9.5
DOB/W ^{1/3}	1.04	1.72	1.5	1.72	1.5
Spacing S (ft)	150	45	8	5.25	13.6
S/W ^{1/3}	1.15	1.31	2.0	1.31	2.14

RATIO OF BLAST PERPENDICULAR TO ROW TO BLAST OFF THE END

Ground - shock - induced					
Peak Overpressure	1.0-3.7	2.5	2.5	5.5	4.75
Gas Venting					
Peak Overpressure	1.0-1.5	1.6-2.1	1.0-1.4	1.4-2.0	2.5
Positive Impulse	0.6-1.8	1.8	1.0-1.25	1.0-1.4	1.8*

RATIO OF BLAST FROM ROW CHARGES TO BLAST FROM SINGLE CHARGE

Perpendicular					
Ground - shock - induced					
Peak Overpressure	1.3-3.7	3.8†	4.3	5.0	4.75
Gas Venting Peak					
Overpressure	0.8-2.8	3.3†	4.1	1.7	5.5
Positive Impulse	1.3-2.8	4.8†	4.7	2.9	4.9*

OFF END OF ROW

Ground - shock - induced					
Peak Overpressure	0.5-1.8	1.0†	2.0	1.0	1.0
Gas Venting					
Peak Overpressure	1.0-2.3	1.4†	3.5	1.0	2.0
Positive Impulse	1.0-2.1	3.5†	4.2	2.3	2.7

*One measurement

†Quality of single charge data below that of other data

BUGGY I. From the table it is clear that there are variations in medium, in type of explosive, in charge size, and in charge burial depth and spacings. The ratio of an airblast parameter measured perpendicular to the row to that measured off the end of the row varies with the parameter and from one shot to another. These variations result from differences in wave shape from one shot to another, and the variation for BUGGY I itself is a result of differences in attenuation rates with distance perpendicular to the row and off the ends of the row.

Comparison with Airblast from Single Charges -- Airblast from five-charge rows is compared with airblast from single charges in Table 4.2. The comparisons for Shots 211-16, 211-44, and pre-CAPSA 5 involve single charges of the same explosive, charge weight, and burial depth. The comparisons for DUGOUT are for the same charge size, medium, and burial depth; but the explosive for the single charge (BUCKBOARD 13) is TNT rather than nitromethane. The airblast from BUGGY I could be compared with that from either DANNY BOY or CABRIOLET. Although the DANNY BOY medium is perhaps more nearly comparable, CABRIOLET, which was detonated in rhyolite rather than basalt, has been chosen for the comparison. Scaled burial depths are essentially the same, both charges are nuclear, and the yield is only about twice the yield of a charge in the BUGGY I row. In using either DANNY BOY or CABRIOLET results for comparison, the results must be scaled to the BUGGY I yield. In this case, as for all scaling of airblast phenomena, cube-root scaling has been used.

Another reason for using CABRIOLET is that the waveforms are quite similar to those of BUGGY I. There are two notable differences. First, the ground-shock-induced peaks for CABRIOLET are about twice the gas-venting peaks. In the case of BUGGY I, gas-venting peaks and ground-shock-induced peaks are about equal off the ends. Perpendicular to the row the ground-shock-induced peaks are greater than those from gas venting. Second, the decrease in pressure between the ground-shock-induced peak and the gas-venting peak falls below ambient for most cases in CABRIOLET records, but in BUGGY I falls below only in the record obtained from WNW-500. To facilitate comparison of CABRIOLET and BUGGY I, the CABRIOLET results, scaled to 1.1 kt, have been added to Figures 4.7 to 4.9 and 4.11 to 4.13.

Another significant element in the comparison between CABRIOLET and BUGGY I is the difference in attenuation rates with distance. In CABRIOLET and the HE events, these rates for each of the three parameters examined have been about as R^{-1} . In BUGGY I, attenuation rates were notably less, generally from $R^{-.65}$ to $R^{-.75}$ off the end of the row, and more nearly approaching R^{-1} perpendicular to the row. These differences, as well as the non-linearity of attenuation rate in the case of BUGGY I, account for the ranges shown in Table 4.2.

Perpendicular to the row, the ratios for BUGGY I, with one exception, are always less than those for the high-explosive charges; this is true for all parameters. Off the ends of the BUGGY I row, the variation in values is too great to permit a generalization. It can be said, however, that the ratios are always less than the largest comparable ratio for the HE shots. These comparisons from Table 4.2 emphasize that predictions of airblast from row charges, based on airblast from single charges of the same yield at the same burial depth, must also take into account differences in medium and charge spacing (energy density per unit length of the row charge).

Since all the airblast data, as well as the CABRIOLET airblast results (and other past nuclear results, as well), have shown an essentially log-log linear attenuation of airblast parameter with distance, the non-linearity of BUGGY I constitutes an exception. The most logical explanation appears to lie in the temperature gradients existing at the time of the BUGGY I shot, which may have tended to refract airblast away from the ground. This could have occurred, for example, if there had been warmer temperatures at the surfaces decreasing rapidly with elevation.

CHAPTER V - SUMMARY AND CONCLUSIONS

Airblast measurements from the BUGGY I nuclear row charge were made in opposite directions off the ends of the row and in opposite directions perpendicular to the center of the row. In contrast to previous work, where airblast measurements have been made over essentially level terrain, the terrain in the vicinity of BUGGY I exhibited extremely pronounced relief. In spite of the gross terrain features, there was almost no evidence of terrain effects on airblast propagation. One slight effect was noted on the calibration shots in the case of the WNW line, where the most distant station was located at the end of an inclined re-entrant canyon.

The effect of temperature gradient was more pronounced in the second calibration shot than in the first, causing greater rates of attenuation with distance for the second shot as a result of warming trends between the first and second firing times. In BUGGY I, attenuation rates were low close to the detonation but increased, particularly at distances beyond 7000 ft, off the ends of the row, and generally throughout the range perpendicular to the row.

Perpendicular to the row, peak ground-shock-induced overpressures range from 1 to 3.7 times those measured off the ends of the row, the range being accounted for by the differences in attenuation rates in the two opposite directions. For peak gas-venting overpressures the range was 1.0-1.5, and for the positive-phase impulses was 0.6-1.8. Off the ends of the row, ground-shock-induced peaks were about equal to gas-venting peak overpressures, and perpendicular to the row the ground-shock-induced peaks were notable larger than those from gas venting.

Although there was pronounced azimuthal asymmetry in peak overpressures at the closer distances, by 6000 feet, peaks were almost azimuthally equal, indicating that circular symmetry was approached.

Peak ground-shock-induced overpressures perpendicular to the row are as much as 3.7 times those scaled from CABRIOLET, while peak gas-venting overpressures and positive-phase impulses are up to 2.8 times those scaled from CABRIOLET. Off the ends of the row the differences were less. Comparison is complicated by the nonuniformity of BUGGY I blast attenuation with distance.

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APPENDICES - PRESSURE-TIME RECORDS

APPENDIX A

CAL 1

BUDDY CAL-1 RHE 500-2

BUDDY CAL-1 RHE 5900-1

BUDDY CAL-1 RHE 1100-1

BUDDY CAL 1 RHE 5900-2

BUDDY CAL-1 SSW 500-2

BUDDY CAL-1 SSW 1000-2

BUDDY CAL-1 SSW 6600-1

BUDDY CAL-1 SSW 2500-2

BUOY CAL-1 BSW 6600-2

BUOY CAL-1 BSW 500-1

BUOY CAL-1 BSW 500-2

ADJUST 1.0

BUOY CAL-1 BSW 1000-1

BUDDY CAL-1 ESE 1000-2

BUDDY CAL-1 ESE 2000-2

BUDDY CAL-1 ESE 7000-1

BUDDY CAL-1 ESE 7000-2

BUOY CAL-1 ESE 9500-1

BUOY CAL-1 NW 500-1

BUOY CAL-1 NW 500-2

BUOY CAL-1 NW 1000-1

BUDDY CAL-1 WNW 1000-2

BUDDY CAL-1 WNW 2000-2

BUDDY CAL-1 WNW 4000-2

BUDDY CAL-1 WNW 8000-2

APPENDIX B

CAL 2

BUDDY CAL-2 RNE 500-1

BUDDY CAL-2 RNE 500-2

BUDDY CAL-2 RNE 8000-2

BUDDY CAL-2 RNE 10500-2

BUDDY CAL-2 SSW 500-2

BUDDY CAL-2 SSW 1000-2

BUDDY CAL-2 SSW 2500-2

BUDDY CAL-2 SSW 6600-1

BUOY CAL-2 BSW 9800-2

BUOY CAL-2 ESE 500-1

BUOY CAL-2 ESE 500-2

BUOY CAL-2 ESE 1000-2

NO CORRECTIONS

BUOY CAL-2 ESE 2000-1

BUOY CAL-2 ESE 2000-2

NO CORRECTIONS

BUOY CAL-2 ESE 7000-1

BUOY CAL-2 ESE 7000-2

BUDDY CAL-2 ESE 9500-1

BUDDY CAL-2 NW 500-2

BUDDY CAL-2 NW 1000-2

BUDDY CAL-2 NW 2000-2

BUGGY CAL-2 MW 4000-2

BUGGY CAL-2 MW 8000-1

BUGGY CAL-2 MW 8000-2

APPENDIX C

BUGGY I

BUDDY HRE 500-1

BUDDY HRE 500-1

BUDDY HRE 500-2

BUDDY HRE 500-2

BUOY NNE 4100-1

BUOY NNE 4100-1

BUOY NNE 4100-2

BUOY NNE 4100-2

BUDDY HNE 5900-1

BUDDY HNE 5900-1

BUDDY HNE 5900-2

BUDDY HNE 5900-2

BUDDY NRE 8000-1

BUDDY NRE 8000-1

BUDDY NRE 8000-2

BUDDY NRE 8000-2

ADJUST 1 .2

BUDDY HNE 105001

BUDDY HNE 105001

BUDDY HNE 105002

BUDDY HNE 105002

BUOY SSW 500-1

BUOY SSW 500-1

BUOY SSW 1000-1

BUOY SSW 1000-1

BUDDY 8SW 1000-2

BUDDY 8SW 1000-2

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BUDDY ESE 2000-2

BUDDY ESE 2000-2

BUDDY ESE 7000-1

BUDDY ESE 7000-1

BUDDY ESE 7000-2

BUDDY ESE 7000-2

BUDDY ESE 9500-1

BUDDY ESE 9500-1

BUOY ESE 9500-2

BUOY ESE 9500-2

BUOY WNW 500-1

BUOY WNW 500-1

BUDDY MW 1000-1

BUDDY MW 1000-1

BUDDY MW 1000-2

BUDDY MW 1000-2

BUGGY MW 2000-1

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