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WT-905

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Operation

CASTLE

[illegible]

March — May 1954

Project 1.2b

GROUND SURFACE AIR PRESSURE VERSUS DISTANCE FROM HIGH YIELD DETONATIONS

Issuance Date: June 7, 1957

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WT--905

OPERATION CASTLE—PROJECT 1.2b (U)

Report to the Scientific Director

GROUND SURFACE AIR PRESSURE VERSUS DISTANCE FROM HIGH YIELD DETONATIONS (U)

J. J. Meszaros
C. N. Kingery

Explosion Kinetics Branch
Terminal Ballistics Laboratory
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

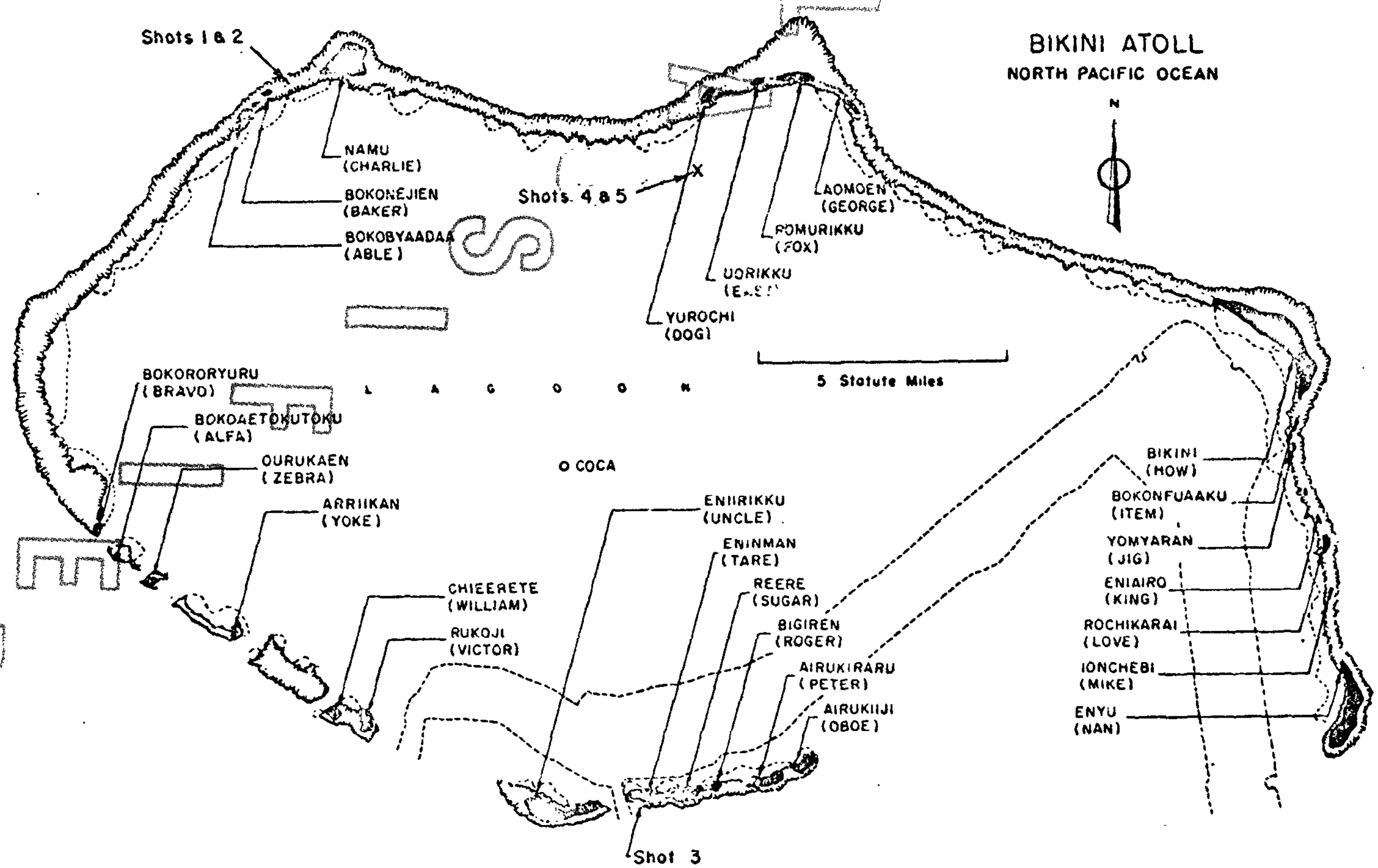
MAY 1957

[redacted]

GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen).		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800.27	N 161,424.43 E 116,688.15	N 147,750.00 E 67,790.00

* APPROXIMATE


BIKINI ATOLL
NORTH PACIFIC OCEAN
N
5 Statute Miles
Shots 1 & 2
NAMU (CHARLIE)
BOKONEJIEN (BAKER)
BOKOBYAADAA (ABLE)
Shots 4 & 5
YUROCHI (DOG)
UORIKKU
ROMURIKKU (FOX)
AOMOEN (GEORGE)
L A G O O N
BOKORORYURU (BRAVO)
BOKOAETOKUTOKU (ALFA)
OURUKAEN (ZEBRA)
ARRIIKAN (YOKE)
O COCA
CHIEERETE (WILLIAM)
RUKOJI (VICTOR)
ENIIRIKKU (UNCLE)
ENINMAN (TARE)
REERE (SUGAR)
BIGIREN (ROGER)
AIRUKIRARU (PETER)
AIRUKIIJI (OBOE)
Shot 3
BIKINI (HOW)
BOKONFUAAKU (ITEM)
YOMYARAN (JIG)
ENIAIRO (KING)
ROCHIKARAI (LOVE)
IONCHEBI (MIKE)
ENYU (NAN)

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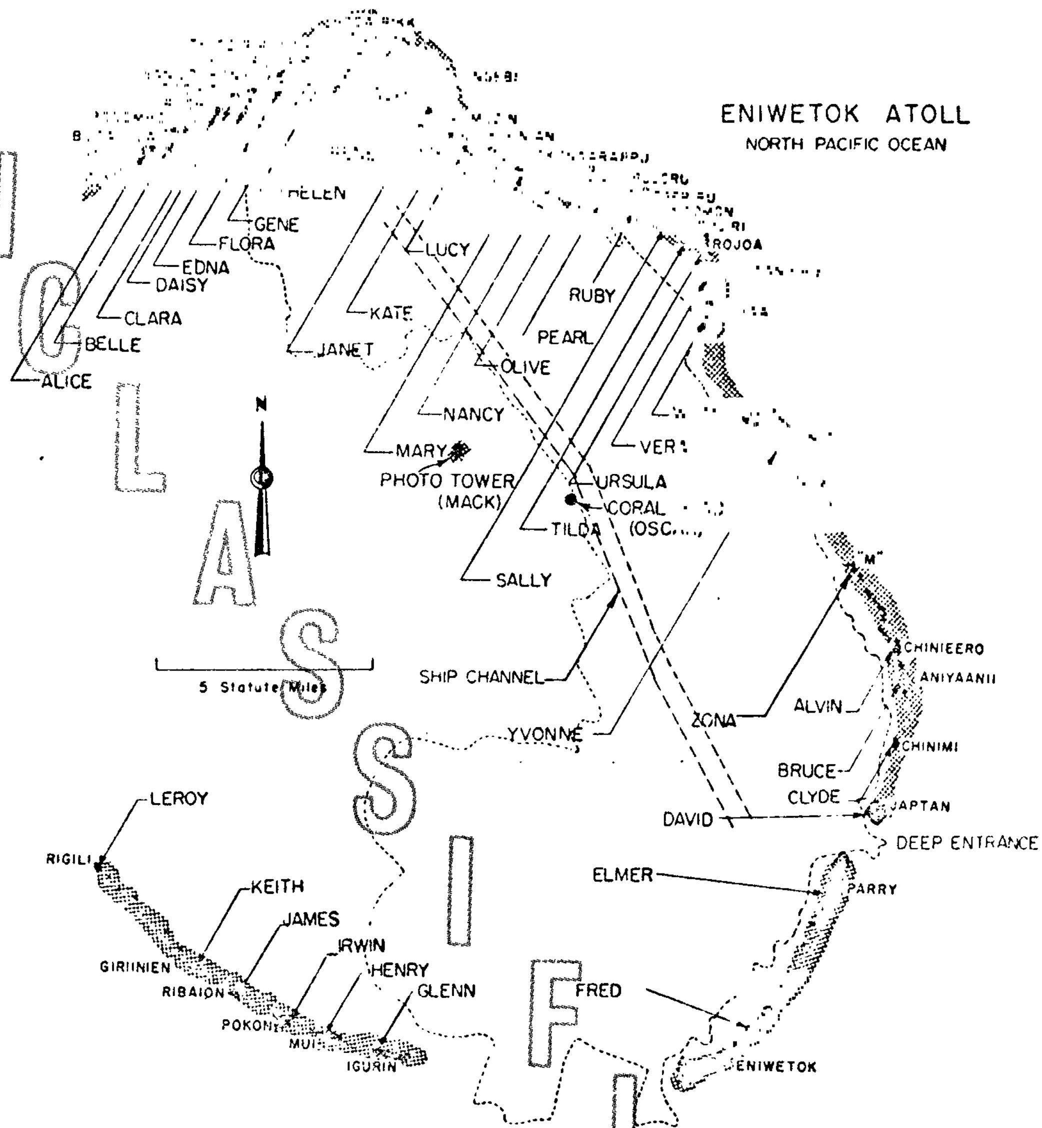

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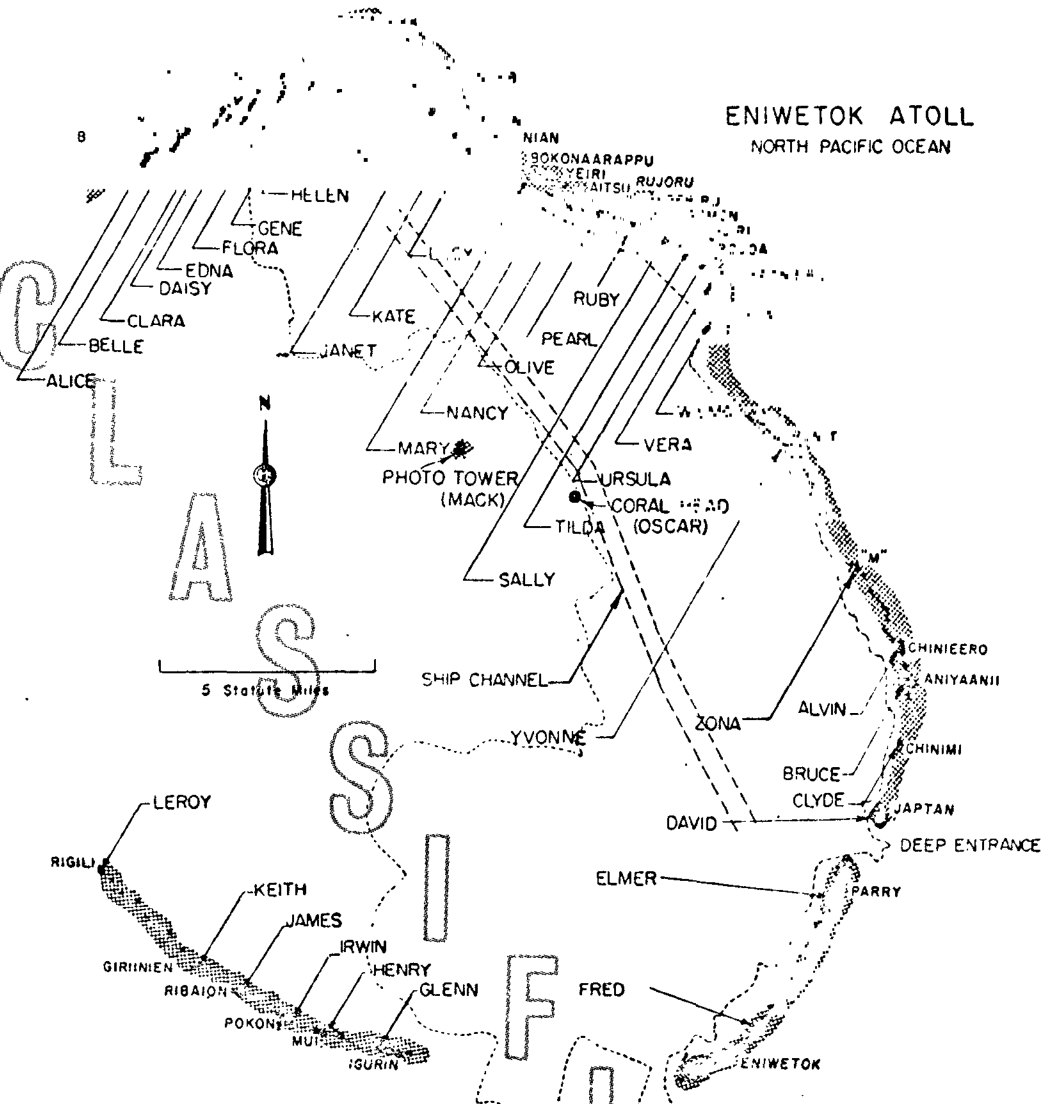
ENIWETOK ATOLL
NORTH PACIFIC OCEAN
NIAN
BOKONAARAPPU
RUJORU
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
BELLE
ALICE
KATE
JANET
RUBY
PEARL
OLIVE
NANCY
MARY
PHOTO TOWER
(MACK)
VERA
URSULA
CORAL
(OSCAR)
TILDA
SALLY
N
5 Statute Miles
SHIP CHANNEL
YVONNE
ZONA
ALVIN
"M"
CHINIEERO
ANIYAANII
CHINIMI
BRUCE
CLYDE
JAPTAN
DAVID
DEEP ENTRANCE
ELMER
PARRY
LEROY
RIGILI
KEITH
JAMES
IRWIN
HENRY
GLENN
GIRIINIEN
RIBAION
MUI
IGURIN
FRED
ENIWETOK

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ABSTRACT

Operation CASTLE presented an opportunity to obtain ~~a wealth of~~ air pressure data in high and low pressure regions from surface bursts of high-yield weapons.

Air-pressure measurements using self-contained, flash-initiated gages were successful. Overpressure data were obtained up to pressure levels of 250 psi.

Dynamic pressure measurements using newly developed self-recording "q" gages were successful. Measurements were obtained over a dynamic pressure range of 0.47 to 135 psi.

Shot 3 produced the only anomalous results. Two distinct curves of pressure versus distance were obtained from the two blast lines instrumented. The blast lines were approximately 180° apart, one being located on the Tare Complex and the other on Site Uncle. The pressures obtained on the Tare Complex line were as much as 20 percent lower than the pressures at comparable distances on Uncle. Evidence exists which seems to indicate that a heavy rainstorm was localized over the Tare Complex at zero time. It would seem possible that a significant reduction in pressures can result when the shock wave passes through an area in which precipitation is occurring.

The validity of the scaling law for yields as great as 15 MT appears to have been substantiated.

The dynamic pressures obtained are apparently in agreement with theoretical values.

When the overpressures obtained on all shots were scaled to 1 KT at sea level and plotted, a 1.6 KT free air curve appeared to be the best fit.

[redacted]

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the military effect tests program of Operation CASTLE, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT-934, Summary of Weapons Effects Tests, military effect program. This summary report includes the following information of possible general interest: (1) An overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots. (2) Discussion of all project results. (3) A summary of each project, including objectives and results. (4) A complete listing of all reports covering the military effect test program.

ACKNOWLEDGMENTS

The advice and guidance of C. W. Lampson and E. E. Minor, Ballistic Research Laboratories and the cooperation of LCDR W. L. Carlson, USN, Director, Program 1, is gratefully acknowledged.

Special acknowledgment is extended to Cpl Eugene A. Levin, A/1C Donald C. Freeswick, A/2C Richard C. Wagner, A/2C Ross N. Tucker, and G. Ginty of the Ballistic Research Laboratories for their excellent work in instrumentation design and development.

Particular and grateful appreciation is extended to the outstanding work of Marvin F. Clarke in instrumentation design and in the preliminary planning on this project while associated with the Ballistic Research Laboratories. Clarke further contributed to the project by personally supervising the gage production in his present capacity as a staff member of the commercial concern which manufactured the gages.

Contributing authors for Appendix B were A/1C D. C. Freeswick, A/2C R. C. Wagner, A/2C R. N. Tucker, and Cpl. R. J. Mudd.

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TABLES

FIGURES

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Chapter 1

INTRODUCTION

1.1 PRIMARY OBJECTIVE

Project 1.2b had as its primary objective the measurement of air-pressure-time versus distance in the high-pressure region. This region was defined for these tests as being between the pressure levels of 40 psi through 200 psi. Improved versions of the self-contained, flash-initiated, mechanical gages, which had been used during Operation UPSHOT-KNOTHOLE were utilized (see Reference 1). The measurements were to extend the scaling laws, to increase fundamental air blast data, and to improve the prediction of blast parameters produced by the detonation of high-yield nuclear weapons.

1.1.1 Secondary Objectives

Secondary objectives of this project were to: (1) obtain pressure-time measurements for Project 3.3 within a tree stand and to relate these to undisturbed medium measurements at similar ground ranges; (2) provide the gages and aid in the analysis of both pressure-time and dynamic pressure data for Project 1.8; (3) provide full-scale tests of newly [illegible] self-recording gages designed for the measurement of dynamic pressures, ground accelerations, and pressure-time; and (4) establish the validity and accuracy of the records obtained by self-contained gages by comparisons with electronically recorded measurements.

1.2 BACKGROUND

The proper evaluation of the military effects of nuclear weapons requires adequate knowledge of the various phenomena which occur during and after the detonation of such weapons. A basic phenomena is the pressure-time-distance variation of air shock waves resulting from the detonations of these weapons. Operation IVY was the first opportunity to study the blast phenomenology of a high-yield device and further the IVY Mike shot was only the second surface burst of a nuclear device. Thus, valuable information was obtained not only in scaling, but also for determining the zero points of the height-of-burst curves. The experimental data on air blast were obtained from Sandia Corporation measurements (see Reference 2). Because of instrumentation difficulties, no data were obtained at pressure levels greater than 20 psi; however, data that were obtained tended to verify the scaling procedure. It was recognized, however, that additional data in the higher pressure regions of a surface burst would be of great value. Therefore, the various shots of Operation CASTLE were instrumented to provide air pressure data in high and low pressure regions from surface bursts of high-yield devices.

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RESTRICTED DATA

Chapter 2
EXPERIMENT DESIGN

The high yields expected, in all shots, required widely scattered measurement stations. These stations, as in IVY, covered island complexes instead of one or possibly two islands as previously utilized during Operations SANDSTONE and GREENHOUSE. An extremely flexible field layout and operational organization was mandatory, because of the widely scattered test areas which were located on both Eniwetok and Bikini Atolls. The flexibility required was further stressed by the modifications made during the course of the operation, not only in expected yield of the shots, but also in the particular shot locations. Many changes in gage ranges and stations were required. As an example, one shot originally planned for Bikini was shifted to Eniwetok. The instrumentation at the new test location was not firmly established until after the cancellation of another shot, planned for Eniwetok, [illegible] completely instrumented. In a matter of a few days all [illegible] from the canceled shot area was recovered and trans- [illegible] with additional new instrumentation to the new location and installed in surveyed stations. All work of station locations, surveying, and installation for this shot was conducted by project personnel.

2.1 STATION AND INSTRUMENTATION

A total of 71 gage stations were used during the operation to obtain data from the six shots. These stations were scattered over 18 islands and along reefs located in the two atolls of the proving grounds; in addition to the instrumentation installed to accomplish the primary objective, many stations were constructed by project personnel to obtain the data required by the secondary objectives. Table 2.1 indicates the number of stations and the number and the types of gages used for each shot.

2.2 FIELD LAYOUT (BLAST LINES)

Predictions of the expected overpressures versus distance were required for each shot in order to locate gage stations in the region of interest as well as to select the proper gage ranges. The composite curve of free-air pressure versus distance [illegible] 2 KT from Operation TUMBLER Shots 1 to 4 (see Reference 3) was [illegible] pressure predictions. The use of this curve for predictions was believed justified by the reasonable correlation with Shot Mike.

The gage stations were located by scaling the distances by the cube root scaling law. The ground distances for the contractor installed stations, 122-series and 123-series, were based upon the average expected yields published for the various shots in the early

TABLE 2.1 - Station and Gage Summary

Shot	No. of Stations	GAGES (Type and Numbers) Pressure Time	Peak Pressure	Dynamic Pressure	Acceleration
1	8	22	7	1	2
2	6	18	6	-	3
3	31	63	7	8	11
4	9	23	7	1	-
5	3	8	-	1	-
6	14	32	-	10	8

NOTE: Of the 71 stations instrumented, 31 were contractor installed, and 40 were project installed.

planning stages of the operation. The gage ranges established for any particular shot were changed accordingly with the predicted yield figures periodically promulgated during the operational phase of the tests. Where a fairly wide range of yield from minimum to maximum was predicted, the gage ranges at any one station were so arranged that at least one gage at each station would operate within its designed pressure range.

2.2.1 Gage Station Types

Four different number-series of stations were used during the various shots, a brief description of each follows:

122-Series: Land Station. This was the basic station, installed by the contractor prior to the arrival of the project in the forward area. These stations [illegible] of four 6-inch-diameter steel-pipe gage mounts, 3 feet long, [illegible] by reinforcing rods and forming a square 2 feet on a side. A 12-inch-square steel plate was welded to the bottom of each to provide bearing surface. The pipes were buried in the ground so that the top of the mount was flush with the surrounding ground surface. The station prior to backfill is illustrated in Figure 2.1.

123-Series: Reef Station. These stations were contractor installed. Three such stations were used and were located along the coral reef between Sites Charlie and Dog. Each station consisted of pipe gage mounts with the same physical arrangement as the 122 series. The pipes were imbedded in drilled holes in the coral presumably to a depth of 10 feet. The height of the pipes above the coral bottom was adjusted so that the top of the pipe was at least 6 inches above the high-tide water level.

124-Series: Land Station. The stations in this series assumed a variety of forms and all were project installed. These stations provided mounts for either "q" gages or pressure-time gages and, in some cases, for both.

No formalized mounting was used for the pressure-time gages. In some cases, pipe mounts were buried with the top flush with the ground

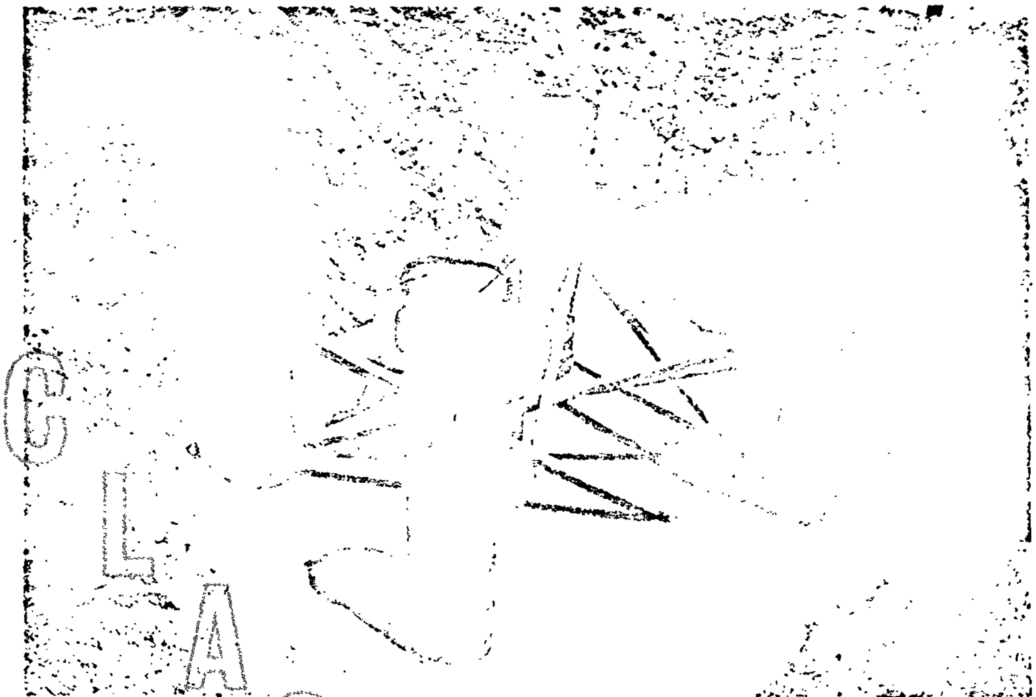

Figure 2.1 122 Series station prior to backfill.

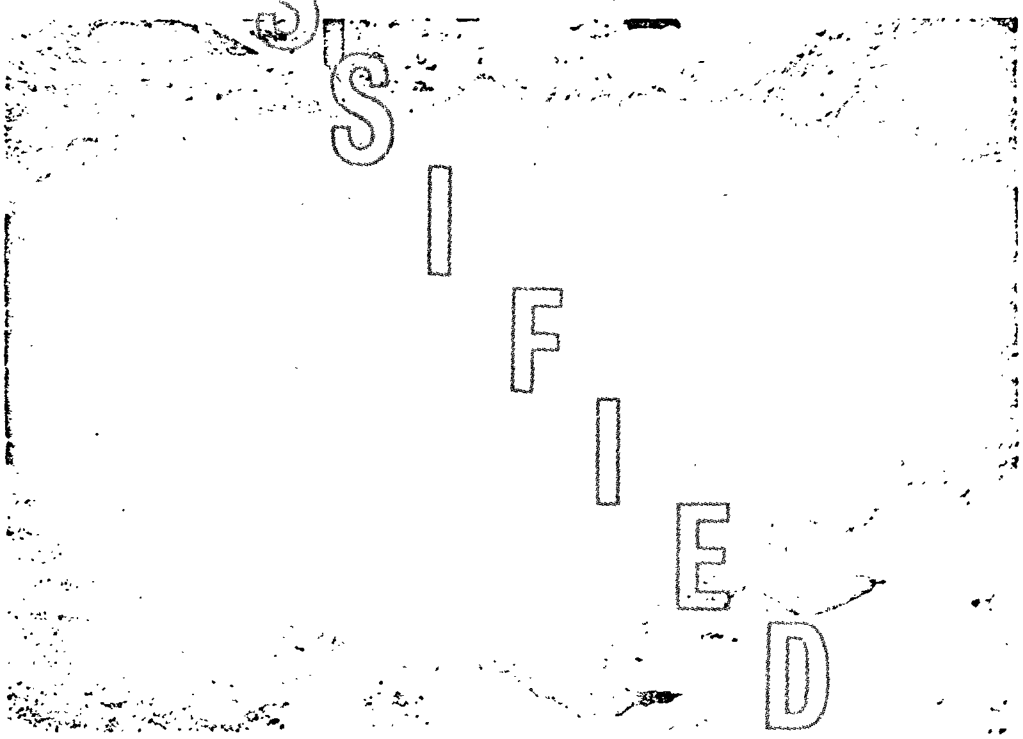

Figure 2.2 One type of 124 Series station during construction.

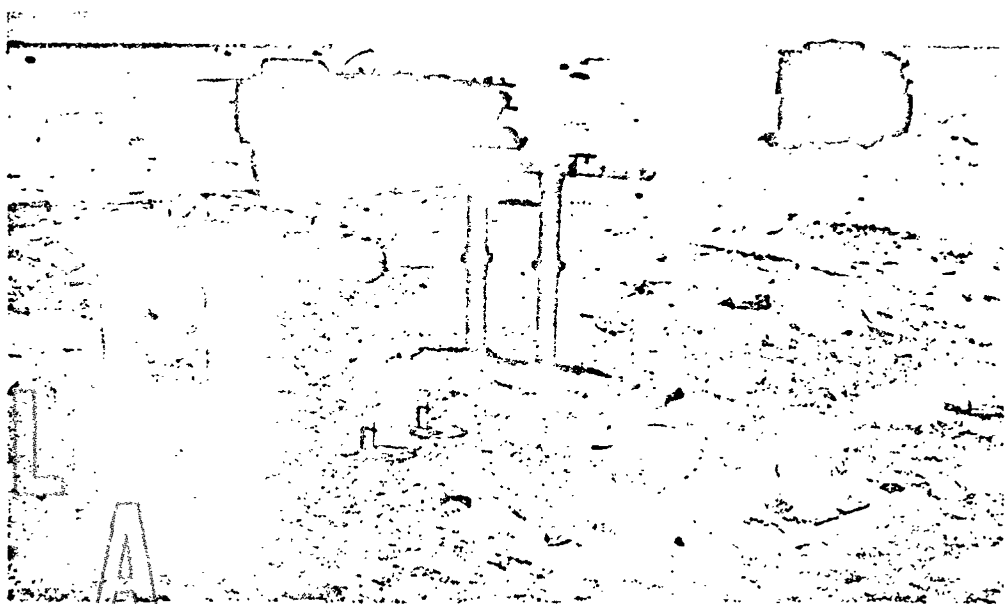

Figure 2.3. Typical 124 Series station with "q" and pressure-time gages installed. Station 124.25, Shot 6.

surface. This type station in the preparation phase is illustrated in Figure 2.2. In other cases, the gages were fitted with a 3-inch pipe 15 inches long, as shown in Figure C.16. A 12-inch-square plate was welded to the bottom of the pipe to provide a bearing surface. The gage and assembled pipe was then buried in the ground with the top of the gage level with the ground surface.

Those stations, at which "q" gages were also located, required the installation of a special mount. This mount consisted of vertical pipes buried in the ground with approximately 2 feet of the pipes projecting above grade. Again, bearing surface was provided by attaching 12-inch-square plates to the base of each pipe. These pipes were accurately leveled and sighted on ground zero to insure proper orientation of the gage.

A typical 124 series station (Station 124-25) consisting of two pressure-time gages and two "q" gages is shown in Figure 2.3.

333-Series: Tree Stand Station. This series of stations was used to instrument the tree stand on Site Uncle for Project 3.3 and was project installed. The description of the 124 series will also serve for these stations.

The station numbers in parenthesis listed in [illegible] 2.4 and 2.5 designate Sandia Corporation stations immediately [illegible] to Project 1.2b stations.

2.2.2 Station Locations

The station locations, ground distances, azimuths from ground zero, and types and numbers of gages used for each shot are indicated in Tables 2.2 through 2.7.

The blast line layouts for the various shots are shown in Figures 2.4 through 2.7.

2.3 INSTRUMENTATION

Instruments were installed to measure the air shock overpressure, the dynamic pressure, and the ground acceleration. All of the gages were self-recording and flash-initiated requiring no external power source or cabling. The design of the instrumentation incorporated the basic ideas of the gages used by Project 3.30 (BRL) during UPSHOT-KNOTHOLE (Reference 1).

TABLE 2.2 - Station Locations, Bikini Atoll, Shot 1

STATION NUMBER	SITE	DISTANCE FROM GZ (ft)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
122.05	Charlie	5420	82° 58' 02"	3	1		1
122.06	Charlie	6260	84° 50' 12"	3	1		
122.07	Charlie	7100	84° 28' 45"	3	1		
122.08	Charlie	7517	66° 24' 42"	3	1		
122.09	Dog	40532	93° 16' 52"	1		1	
123.01	Reef East of Charlie	9610	84° 06' 21"	3	1		
123.02	Reef East of Charlie	12871	92° 43' 04"	3	1		
123.03	Reef East of Charlie	15925	95° 47' 48"	3	1		1

NOTE: P_t = Pressure Time; P_p = Peak Pressure; q = Dynamic Pressure; A = Acceleration

TABLE 2.3 - Station Locations, Bikini Atoll, Shot 2

STATION NUMBER	SITE	DISTANCE FROM GZ (ft)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
122.05	Charlie	5630	83° 24' 51"	3	1		1
122.06	Charlie	6471	85° 09' 53"	3	1		
122.07	Charlie	7311	84° 46' 47"	3	1		1
122.08	Charlie	7707	67° 10' 08"	3	1		
123.02	Reef East of Charlie	13085	92° 45' 06"	3	1		
123.03	Reef East of Charlie	16140	95° 47' 00"	3	1		1

NOTE: P_t = Pressure Time; P_p = Peak Pressure; q = Dynamic Pressure; A = Acceleration

The common feature of the three types of pressure-time gages, the peak pressure gage, and the dynamic pressure gage was the nested

[redacted]

TABLE 2.4 - Station Locations, Bikini Atoll, Shot 3

STATION NUMBER	SITE	DISTANCE FROM GZ (ft)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
122.15	Uncle	3970	252° 15' 49"	4			
122.16	Tare	2501	88° 07' 10"	3	1		
122.17	Tare	2850	89° 08' 22"	3	1		1
122.18	Uncle	4590	252° 15' 49"	3	1		
122.19	Uncle	5420	252° 15' 49"	3	1		1
122.20	Uncle	6520	252° 15' 49"	3	1	1	1
122.21	Uncle	9380	252° 15' 49"	3	1	1	1
122.22	Uncle	9380	267° 16' 11"	3	1		
124.04 (120.06)	Oboe	17000	78° 25' 35"	2			
124.05 (120.07)	Peter	14300	80° 41' 56"	2			
124.06 (120.08)	Peter	12200	83° 12' 48"	2			1
124.07 (120.09)	Peter	10900	84° 41' 57"	2			1
124.08 (120.10)	Roger	8800	84° 37' 54"	2			
124.09 (120.11)	Roger	7400	83° 55' 30"	2			
124.10 (120.12)	Sugar	6300	85° 00' 49"	2			
124.11 ([illegible])	Sugar	5596	84° 28' 44"	2			2
[illegible] ([illegible])	Sugar	3657	86° 37' 19"	2			1
124.13 (130.01)	Peter	10900	84° 45' 06"			1	
124.14 (130.02)	Roger	8800	84° 43' 47"			1	
124.15 (130.03)	Roger	8200	83° 23' 37"			1	
333.01	Uncle	8048	257° 48' 00"	2			
333.02	Uncle	8205	259° 02' 33"	2		1	1
333.03	Uncle	8292	259° 59' 05"	2			
333.04	Uncle	8807	259° 01' 13"	3			
333.05	Uncle	9408	258° 58' 07"	3		1	
333.06	Uncle	9891	257° 47' 59"	2			
333.07	Uncle	10008	258° 57' 29"	2			
333.08	Uncle	10415	259° 58' 40"	2			
333.09	Victor	28427	286° 57' 40"	1		1	
333.10	William	31308	286° 25' 41"	1			1
180.09	Uncle	6500	252° 15' 49"			1	

NOTE: P_t = Pressure time
P_p = Peak pressure
q = Dynamic pressure
A = Acceleration

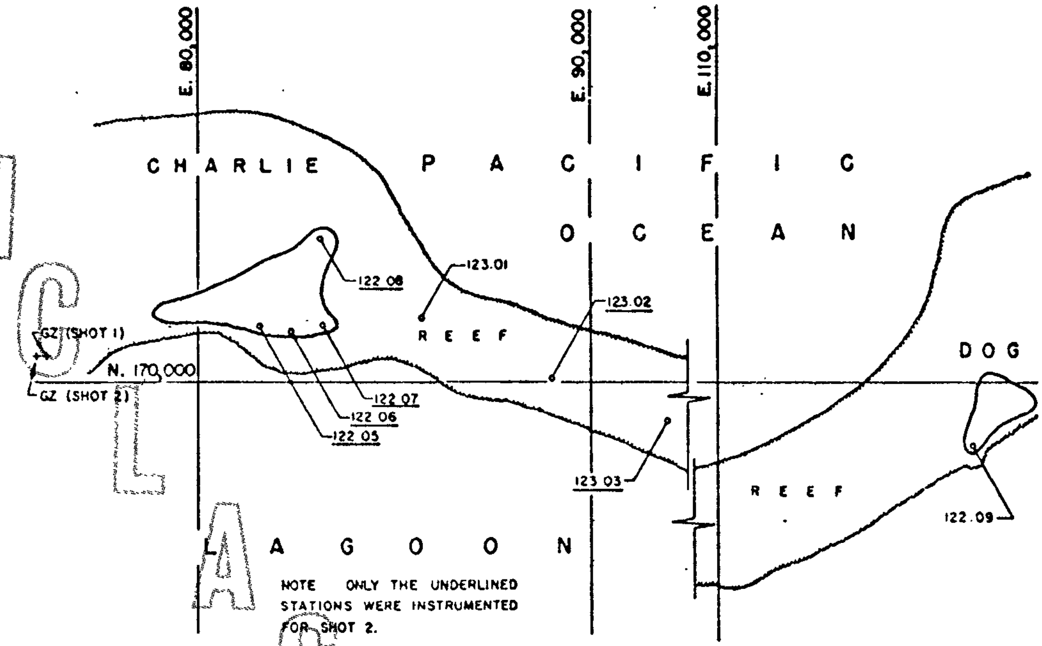

Figure 2.4 Blast line layout, Shots 1 and 2.

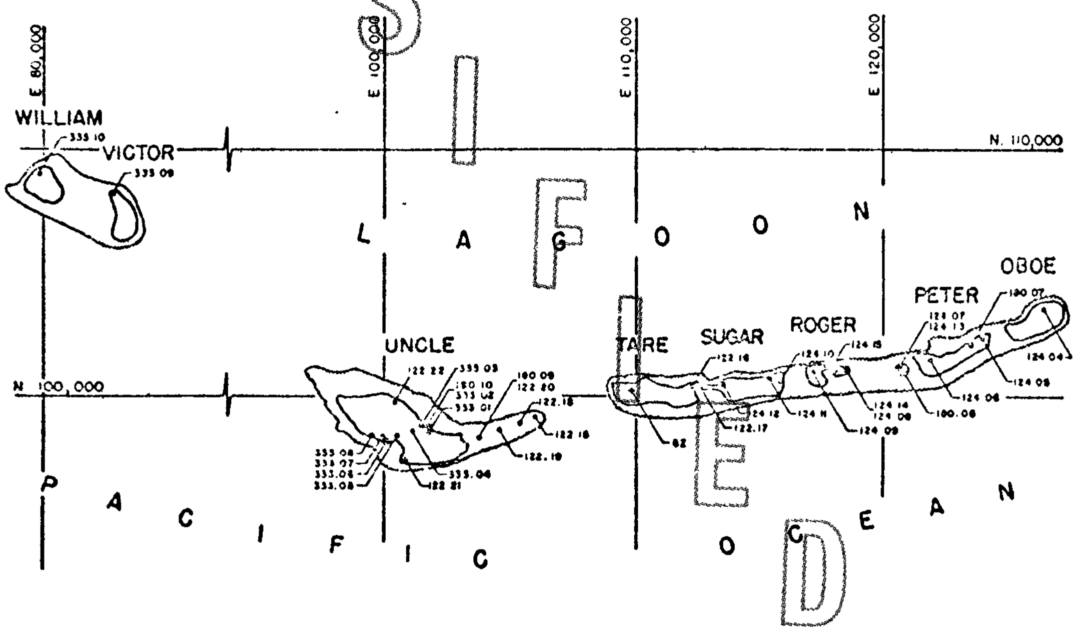

Figure 2.5 Blast line layout, Shot 3.

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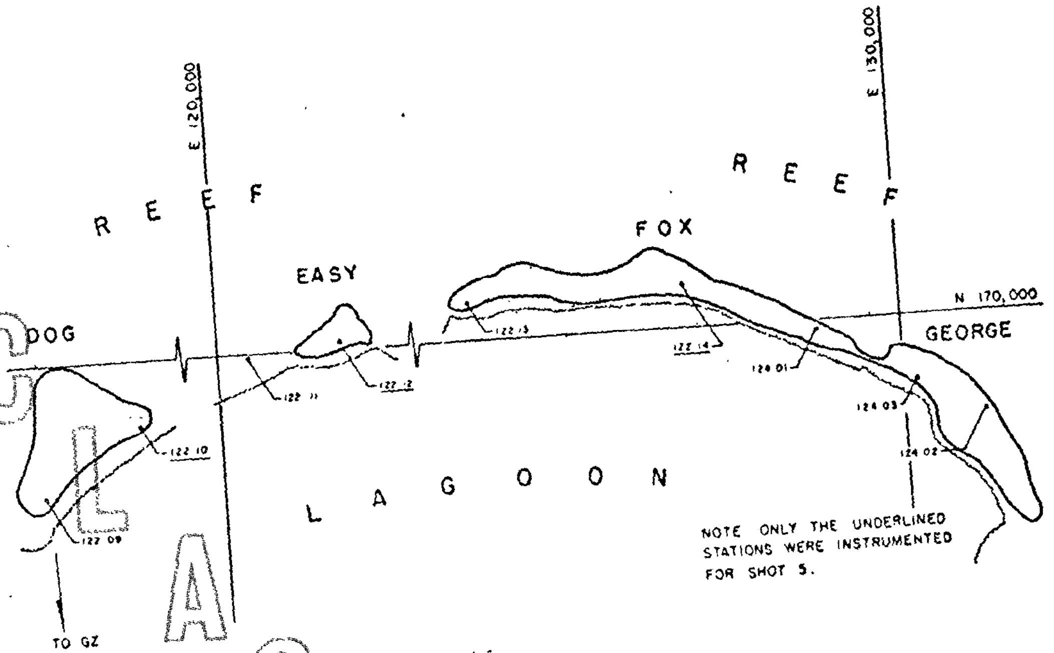

Figure 2.6 Blast line layout, Shots 4 and 5.

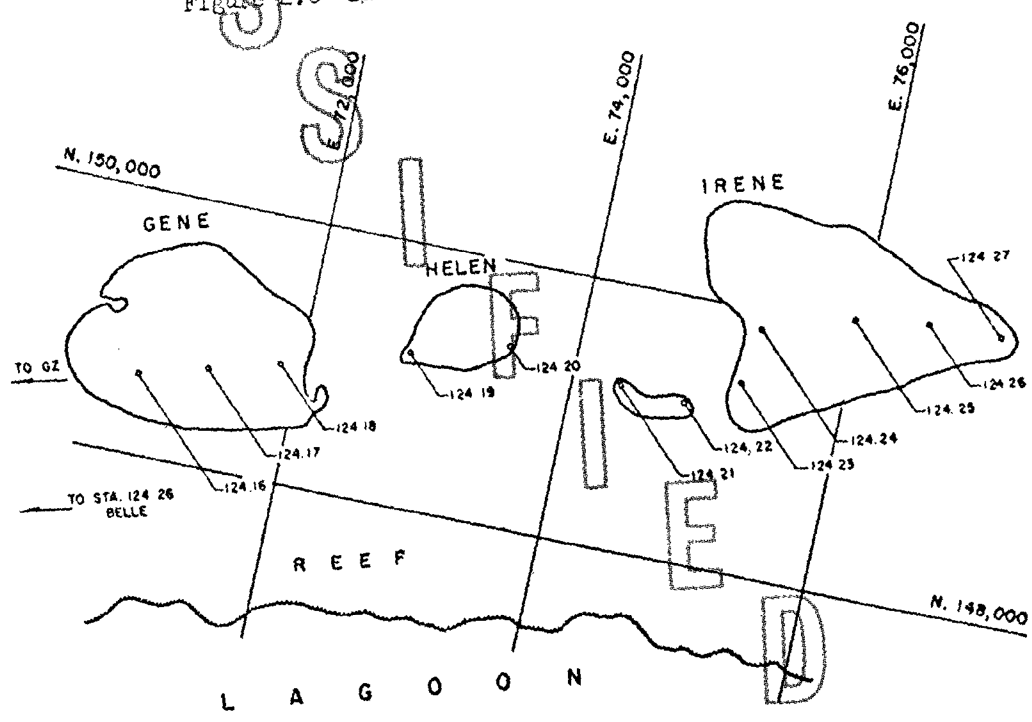

Figure 2.7 Blast line layout, Shot 6.

[redacted]

TABLE 2.5 - Station Locations, Bikini Atoll, Shot 4

STATION NUMBER	SITE	DISTANCE FROM GZ (FT)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
122.09	Dog	6600	358° 31' 13"	3	1		
122.10	Dog	7500	9° 42' 32"	3	1		
122.11	Dog-Easy	9000	24° 14' 37"	3	1		
122.12	Easy	9900	31° 36' 17"	3	1		
122.13	Fox	11460	38° 50' 27"	3	1		
122.14	Fox	13396	48° 23' 33"	3	1	1	
124.01 (120.04)	Fox	14500	55° 29' 00"	2	1		
124.02 (120.05)	George	15900	64° 04' 43"	2			
124.03 (130.07)	George	15426	60° 54' 09"	1			

TABLE 2.6 - Station Locations, Bikini Atoll, Shot 5

STATION NUMBER	SITE	DISTANCE FROM GZ (FT)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
122.10	Dog	7789	10° 10' 53"	2			
122.12	Easy	10192	31° 20' 00"	2			
122.14	Fox	13663	47° 50' 40"	4		1	

NOTE: P_t = Pressure-time
P_p = Peak pressure
q = Dynamic pressure
A = Acceleration

diaphragm pressure sensing element. The element was interchangeable between gage types and was available in various pressure ranges from 0-1 psi to 0-400 psi (see Appendix B).

The earth acceleration was obtained by installing special acceleration elements in the pressure-time gage. Any movement of the elements was scratched on the recording disk of the gage (see Appendix E).

An extremely low-pressure gage was used for [illegible] pressure-time phenomenon at distances from 30 to 180 miles from the detonation point. One gage of this type was placed beside the Sandia Corporation's

[redacted]

TABLE 2.7 - Station Locations, Eniwetok Atoll, Shot 6

STATION NUMBER	SITE	DISTANCE FROM GZ (FT)	AZIMUTH FROM GZ	TYPE AND NUMBER OF MEASUREMENTS			
				P_t	P_p	q	A
124.16	Gene	3200	74° 20' 26"	3		1	1
124.17	Gene	3700	74° 20' 37"	3			
124.18	Gene	4200	74° 20' 27"	3		1	
124.19	Helen	5200	74° 20' 28"	3			1
124.20	Helen	5900	74° 20' 36"	2		1	1
124.21	Irene	6744	77° 22' 43"	2		1	1
124.22	Irene	7234	78° 26' 44"	2			1
124.23	Irene	7600	77° 22' 22"	2		1	1
124.24	Irene	7900	74° 20' 49"	2		1	1
124.25	Irene	8501	74° 20' 59"	2		2	
124.26	Irene	8992	74° 57' 55"	2		1	
124.27	Irene	9584	75° 37' 21"	2		1	1
124.28	Belle	13089	240° 55' 42"	2			
x	Elmer	113752	144° 55' 46"	2			

NOTE: P_t = Pressure-time

P_p = Peak pressure

q = Dynamic pressure

A = Acceleration

microbarograph station on Site Elmer for all test shots fired on Bikini Atoll. On a number of test shots, another gage was located on one of the task force ships. Although these measurements were made with experimental gages, the results appear to be accurate (see Appendix F).

[redacted]

Chapter 3
RESULTS

3.1 SHOT 1

3.1.1 Recovery

Of the 32 gages used to instrument Shot 1, all but four were recovered. Station 123.01, the reef station nearest ground zero, was blown out of the coral. Neither the gages nor the mounts were found after the shot.

3.1.2 Records

All records on Station 122.05, the station nearest ground zero, were discounted because excessive overpressure caused the pressure capsules to split. All pressure capsules used at Station 122.06 were stressed approximately 75 percent above their rated range. This caused a permanent set in the diaphragm, and the stylus did not return to the zero baseline. Pressure capsules of the same range were calibrated to 100 percent above their rated range in an attempt to evaluate records from this station. Results obtained by this method may be in error as much as ± 15 percent. The records of pressure versus time from the remaining statio[illegible] for obtaining positive-phase durations, because of the [illegible] of hash present on the records. Excessive hash and high-f[illegible]llations present on the records are thought to be due to turntable wobble caused by poor bearings and lack of precision workmanship in the gage assembly.

3.1.3 Presentation of Data

The station numbers, distances, arrival times, duration of positive phase, and peak overpressures where obtained are listed in Table 3.1. All pressure readings are listed, although some readings are questionable. Brief explanations regarding the reliability of the reading, type of reading, and functioning of the gage have been included under the remarks column. A curve of pressure versus distance is presented in Figure 3.1. The points plotted are averages of values from records considered to be reliable. Values for arrival time versus distance are listed in Table 3.1, but have not been plotted. These values may be less than those obtained by electronic measurements because of the delay in the fusible link initiation system. No plot has been attempted for the positive phase durations because of the scatter and need of a better method of determining these values.

The values of the peak overpressure have been reduced to 1 KT at sea level and plotted in Figure 4.1, along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.2 SHOT 2

3.2.1 Recovery

Gages and records were recovered from all positions instrumented, except positions C and D of Station 122.07. The gage mount was

TABLE 3.1 - Results of Shot 1

Station and Position	Site	Distance from GZ (ft) Actual	Distance from GZ (ft) A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
122.05 A	Charlie	5420	218	300-150	- -	- -	- -	Capsule split disk broken
B				259-150	- -	- -	- -	Capsule split
C				306-200	- -	- -	- -	Capsule split
D				302-150	- -	- -	- -	Capsule split
122.06 A		6260	252	238-150	267	- -	- -	Questionable P-T
B				276-150	260 *	0.5	3.22	Questionable P-T
C				236-150	256 *	0.34	3.25	Questionable P-T
D				293-150	45	- -	- -	Stylus did not record
122.07 A		7100	286	296-150	163 *	- -	- -	Incomplete P-T record, peak reading only
B				170-50	141	- -	- -	Capsule overstressed-record discounted
C				285-150	180 *	- -	- -	Peak pressure only
D				278-150	201	0.58	- -	Questionable P-T record discounted
122.08 A		7517	303	168-50	120 *	0.55	- -	Gage stopped when shock hit - P.P. only
B				250-150	129 *	0.58	4.55	Poor P-T record
C				287-150	119 *	- -	- -	Peak pressure only
D				178-50	80	- -	- -	Questionable record discounted
122.09 A	Dog	40532	1633	12-5	4.5	13.4	8.83	Good P-T record
123.01		9610	387		- -	- -	- -	Gages and mounts were blown out of the station and were not recovered
123.02 A		12871	519	69-25	31.0 *	2.0	3.8	Fair P-T record
B				67-25	35.5 *	2.01	3.7	Fair P-T Record
C				64-25	33.0 *	- -	3.05	Gage started when shock hit
D				86-25	31.0 *	- -	- -	Peak pressure only
123.03 A		15925	642	82-25	19.2 *	- -	- -	Peak pressure only
B				85-25	19.1 *	- -	- -	Poor P-T record
C				87-25	20.0 *	3.48	4.58	Fair P-T record
D				65-25	18.2 *	3.69	4.66	Good P-T record

NOTE: A mean average was taken of these values for plotting a pressure vs distance curve.

blown into the lagoon, and only two gages from that station were recovered.

3.2.2 Records

The installation of the gages for Shot 2 was accomplished at the same time the gages from Shot 1 were recovered. Therefore, the records from Shot 2 had the same possible sources of error from gage assembly as mentioned in Shot 1. One source of error not present on

[redacted]

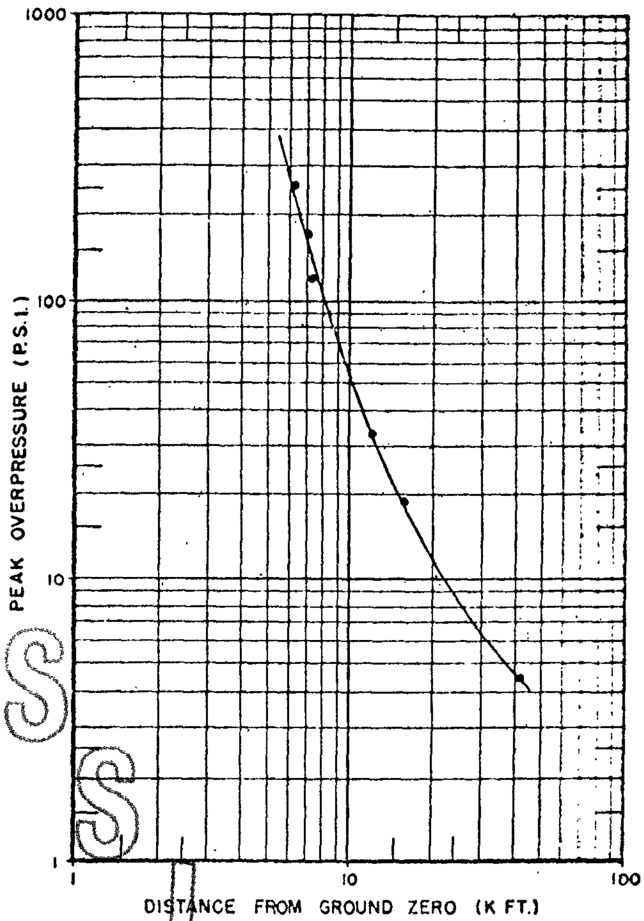

Figure 3.1 Ground surface pressure versus distance, Shot 1.

Shot 2 was that of overstressing the pressure capsule because of a greater yield than expected. Although the yield was less than Shot 1, the gages apparently received greater acceleration, judging from the high frequency oscillation on the records and the facts that some of the gages stopped when hit by the shock and, also, that one of the glass recording disks was broken. It is possible that most of this was due to using the same mounts, which may have been shaken loose by Shot 1.

3.2.3 Presentation of Data

The station numbers, distances, arrival times, duration of positive phase, and peak overpressure, where obtained, are listed in Table 3.2. A curve of pressure versus distance is plotted in Figure 3.2. The points plotted are averages of readings from each station. Arrival times versus distance from ground zero are listed in Table

[redacted]

TABLE 3.2 - Results of Shot 2

Station and Position	Site	Distance from GZ (ft) Actual	A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
122.05 A	Charlie	5630	252	326-200	- -	- -	- -	Recording disk broken
B				346-400	200	- -	- -	Gage stopped when shock hit - P.P. only
C				253-150	215	- -	- -	Ran preshot time - P.P. only
D				249-150	186	- -	- -	Peak pressure only
122.06 A		6471	290	322-200	191	0.18	1.11	Questionable P-T
B				277-150	171	- -	- -	Questionable P.P.
C				251-150	150	- -	- -	Questionable P.P
D				10-100	115	- -	- -	Peak pressure only
122.07 A		7311	328	271-150	96	- -	- -	Questionable P.P.
B				81-100	95	- -	- -	Questionable P-T
C				- -	- -	- -	- -	Gage not recovered
D				---	- -	- -	- -	Gage not recovered
122.08 A		7707	345	3-100	91	- -	- -	Questionable P.P.
B				- -	- -	- -	- -	Water entered gage-coating off disk
C				19-100	102	0.17	2.35	Questionable P-T
D				176-50	62.5	- -	- -	Peak pressure only
123.02 A		13085	586	31-15	25.2	- -	- -	Peak pressure only
B				63-25	- -	- -	- -	Can find no record on disk
C				77-25	18.2	3.44	3.36	Discount record - inlet hole clogged
123.02 D	Charlie	13085	586	27-15	25.3	- -	- -	Peak pressure only
123.03 A		16140	723	51-15	12.0	3.83	3.91	Discount record-inlet hole clogged
B				21-15	15.2	- -	- -	Ran preshot time - P.P. only
C				30-15	16.0	- -	4.33	Good P-T
D				7-10	16.0	- -	- -	Peak pressure only

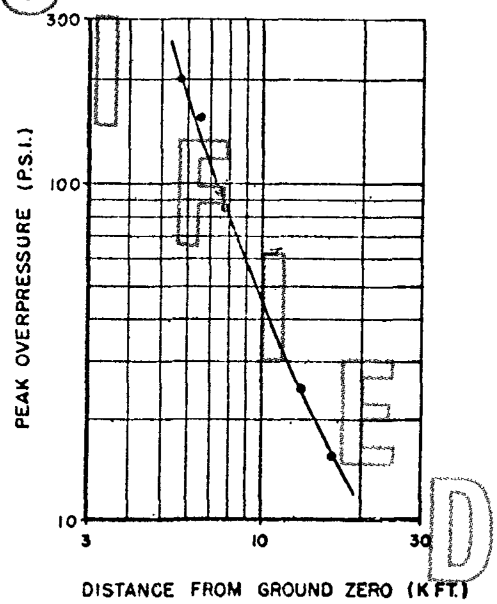

Figure 3.2 Ground surface pressure versus distance, Shot 2.

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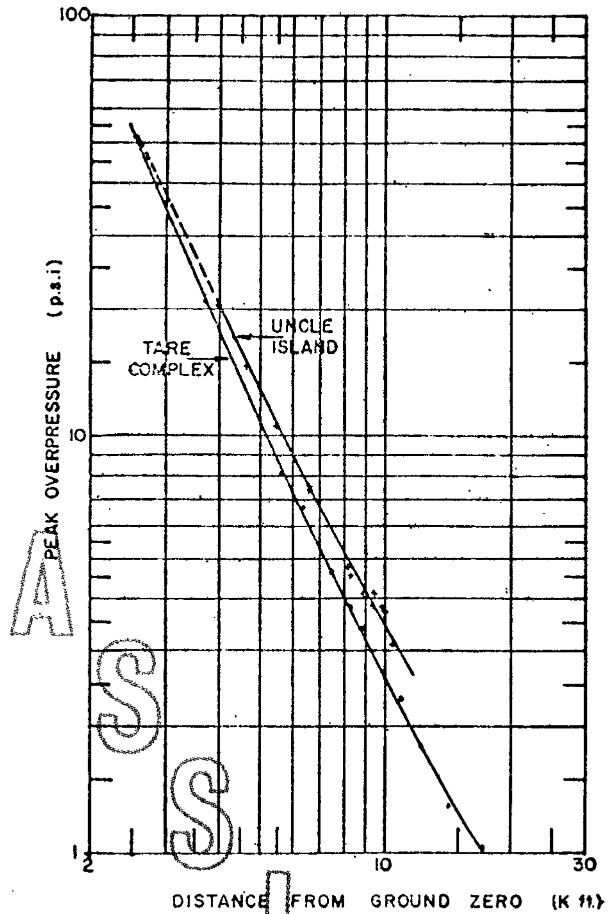

Figure 3.3 Ground surface pressure versus distance, Shot 3.

3.2, but have not been plotted. These values should not be used for drawing conclusions of any kind, owing to the lack of a time constant for the lag in the thermal initiators.

The values of the peak overpressure have been reduced to 1 KT at sea level and plotted in Figure 4.1, along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.3 SHOT 3

3.3.1 Recovery

Of the 31 stations instrumented on Shot 3, ~~all~~ gages and records were recovered. Due to the low yield, there was no damage to the gages or mounts.

3.3.2 Records

There were 26 records out of a total of 84 which cannot be

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read. The clock gages used in the tree stand for Project 3.3 accounted for 11 of the 27. These gages were recovered later than the others, due to the radiation level on Site Uncle. Condensation of moisture on the inside of the gage caused the aluminized coating to peel, leaving no trace.

All records had small deflections, which increased the percentage of error. It is felt that even with the small deflections, the pressures presented are accurate to ± 10 percent.

3.3.3 Presentation of Data

The pertinent data for Shot 3 are listed in Table 3.3. Project 1.2b instrumented blast lines on the Tare Complex and on Site Uncle, which were approximately 180 degrees apart. The pressure values from the two blast lines are plotted in Figure 3.3. Here can be seen two distinct curves, one from stations on Tare Complex and one from stations on Uncle. The value of the pressures obtained on the Tare Complex run as much as 20 percent less than pressures at comparable distances on Uncle. It appears that there was considerable attenuation of the shock wave pressure due to a rainstorm on the Tare Complex which was not present on Uncle. This will be further discussed in Chapter 4.

The values of the peak overpressure have been reduced to 1 KT at sea level and plotted in Figure 4.1, along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.4 SHOT 4

3.4.1 Recovery

On Shot 4 there were 31 gages used to instrument the Dog Complex. Of the 31 gages used, all but seven were recovered. Station 122.13 was completely lost*, and three gages from Station 122.11 were not recovered. The mounts and gages from five of the nine stations were blown or washed out of position and over the islands and reef on the ocean side. Most of the gages were recovered by using a helicopter, although it was necessary to use a DUKW to recover those in the ocean.

3.4.2 Records

Of the 24 records recovered all but three were readable. All pressure-time gages used on Shot 4 had been modified. A detailed description of the modification can be found in Appendix B. Although

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* On Operation REDWING three of the four gages from Station 122.13 were recovered. Although the gages had been submerged in water for over two years, there was no evidence of water in the gage. The records were good and when the cut-off switch was disengaged, the motor still operated from the original battery.

[redacted]

TABLE 3.3 - Results of Shot 3

Station and Position	Site	Distance from GZ (ft)		Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
		Actual	A-Scaled					
122.16 A	Tare	2501	493	338-400	50.0	- -	- -	Gage did not run; reading questionable.
B				354-400	50.0	- -	- -	Ran preshot time; P.P. only.
C				343-400	55.0	0.125	0.597	Fair P-T record
D				333-400	- -	- -	- -	No readable record
122.17 A	Tare	2850	561	316-200	35.0	- -	- -	Poor P-T record
B				330-200	45.0	- -	- -	Questionable
C				353-400	- -	- -	- -	No readable record
D				350-400	- -	- -	- -	No readable record
124.04 L	Oboe	17000	3349	4-5	0.97	- -	- -	Did not start; P.P. only
R				18-5	1.08	- -	- -	Fair P-T record
124.05 L	Peter	14300	2817	10-5	1.2	- -	- -	Did not run, poor P.P.
R				45-15	1.4	- -	- -	Good P-T record
124.06 L	Peter	12200	2403	6-10	1.8	- -	- -	Ran preshot time; P.P. only
R	Peter			5-10	- -	- -	- -	Ran preshot time; no record
124.07 L	Peter	10900	2147	59-15	2.36	- -	- -	Did not run; P.P. only
R				43-15	- -	- -	- -	Ran preshot time; no record
124.8 L	Roger	8800	1734	41-15	3.5	- -	- -	Did not run, P.P. only
R				89-25	- -	- -	- -	Ran preshot time; no record
124.09 L	Roger	7400	1458	223-50	4.6	- -	- -	Good P-T record
R				173-50	- -	- -	- -	Ran preshot time; no record
124.10 L	Sugar	6300	1240	198-50	6.8	2.07	1.36	Good P-T record
R				211-50	6.7	- -	- -	Good P-T record
124.11 L	Sugar	5596	1102	206-50	8.1	- -	- -	Good P-T record
R				186-150	- -	- -	- -	No readable record
124.12 L	Sugar	3657	720	327-200	- -	- -	- -	No readable record
R				308-200	21.0	- -	- -	Good P-T record
124.13 Xq_s	Peter	10900	2147	25-15	2.3	- -	- -	Fair P.P. reading
Xq_t				32-15	2.9	- -	- -	Fair P.P. reading
124.14 Xq_s	Roger	8800	1734	60-15	3.25	- -	1.58	Good P-T record
Xq_t				44-15	3.75	- -	1.58	Good P-T record
124.15 Xq_s	Roger	8200	1615	48-15	3.80	- -	1.52	Good P-T record
Xq_t				35-15	3.27	- -	1.53	Good P-T record
122.15 A	Uncle	3970	782	272-150	20.5	1.17	0.89	Fair P-T record
B				281-150	20.0	- -	- -	Ran preshot time; P.P. only
C				265-150	20.4	0.83	1.19	Fair P-T record
D				294-150	- -	- -	- -	No readable record
122.18 A	Uncle	4590	904	246-150	- -	- -	- -	Ran preshot time; no readable record
B				213-50	14.9	- -	- -	Ran preshot time; P.P. only
C				290-150	14.5	- -	- -	Ran preshot time; P.P. only
D				309-200	- -	- -	- -	Deflection too small
122.19 A	Uncle	5420	1068	234-50	10.8	1.61	0.577	Good P-T record
B				293-150	- -	- -	- -	Ran preshot time; no record
C				291-150	10.3	- -	- -	Poor P-T record; small deflection
D				237-150	- -	- -	- -	Deflection too small to read

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TABLE 3.3 - Results of Shot 3 (cont'd)

Station and Position	Site	Distance from GZ (ft) Actual	Distance from GZ (ft) A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
122.20 A	Uncle	6520	1284	231-50	7.5	2.083	1.00	Good P-T record
B				175-50	7.4	- -	- -	Ran preshot time; fair P.P.
C				184-50	7.4	2.230	- -	Fair P-T; small deflection
D				191-50	7.5	- -	- -	Good P.P. record
122.21 A	Uncle	9380	1848	50-15	3.9	4.30	1.60	Good P-T record
B				57-15	3.6	- -	- -	Ran preshot time; P.P. only
C				111-25	3.9	- -	- -	Ran preshot time; P.P. only
D				71-25	4.1	- -	- -	Fair P.P. record
Xq				23-15	3.6	- -	- -	Peak reading only
122.22 A	Uncle	9380	1848	117-25	3.8	- -	- -	Fair peak reading
B				58-15	3.9	- -	- -	Fair peak reading
C				122-25	3.9	3.85	1.64	Good P-T record
D				74-25	3.9	- -	- -	Good P.P. record
333.01 L	Uncle	8049	1586	29-15	4.7	3.16	1.50	Good P-T record
R				75-15	4.7	2.81	1.51	Good P-T record
333.02 L	Uncle	8205	1616	88-25	- -	- -	- -	Ran preshot time; no record
R				154-25	4.5	3.21	1.56	Good P-T record
Xq				34-15	4.43	- -	1.20	Good P-T record
Xq				39-15	5.20	- -	1.4	Good P-T record
333.03 L	Uncle	8292	1634	28-15	- -	- -	- -	Ran preshot time; no record
R				80-25	4.5	3.59	1.79	Good P-T record
333.04 L	Uncle	8807	1735	10-15	- -	- -	- -	Ran preshot time, no record
R				115-25	- -	- -	- -	Ran preshot time, no readable record
T				18-15	4.2	- -	- -	Good P.P. record
333.05 L	Uncle	9408	1853	20-15	- -	- -	- -	Ran preshot time, no record
R				96-25	- -	- -	- -	Ran preshot time; no record
T				136-25	- -	- -	- -	No readable record
Xq				33-15	4.1	- -	- -	Good P.P. reading
Xq				49-15	- -	- -	- -	P.P. only; overshoot no good
333.06 L	Uncle	9891	1948	2-15	- -	- -	- -	Ran preshot time; no record
R				54-15	3.8	- -	- -	Good P.P. reading
333.07 L	Uncle	10008	1972	38-15	- -	- -	- -	Ran preshot time; no record
R				37-15	3.7	- -	- -	Fair P.P. reading
333.08 L	Uncle	10415	2052	19-15	- -	- -	- -	Ran preshot time; no record
R				52-15	3.2	- -	- -	Peak pressure reading
333.09 T	Victor	28427	5600	2-5	1.12	- -	- -	Questionable P-T record
Xq_s				16-5	.79	- -	- -	P.P. reading only
Xq_d				17-5	- -	- -	- -	P.P. reading; overshoot not readable
333.10 T	William	31308	6168	11-5	- -	- -	- -	No readable record
180.09 Xq_s	Uncle	6500	1280	194-50	7.48	- -	1.2	Good P-T record
Xq_d				172-50	8.60	- -	1.4	Good P-T record

[redacted]

TABLE 3.4 - Results of Shot 4

Station and Position	Site	Distance from GZ (ft) Actual	Distance from GZ (ft) A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
122.09 A	Dog	6600	343	189-50	- -	- -	- -	Water entered gage, coating peeled
B				174-50	94.0	0.257	2.407	Fair P-T record
C				188-50	94.5	- -	- -	Started when shock hit
D				247-50	94.2	- -	- -	Peak pressure only
122.10 A		7500	390	215-50	- -	- -	- -	No record, bad coating on drum
B				179-50	75.5	- -	- -	Ran preshot time; P.P. only
C				220-50	72.2	0.252	2.790	P-T record, flat top
D				171-50	70.0	- -	- -	Peak pressure record
122.11 A	Dog-Easy	9000	468	210-50	46.2	- -	- -	Ran preshot time, P.P. only
B				203-50	- -	- -	- -	Not recovered
C				217-50	- -	- -	- -	Not recovered
D				181-50	- -	- -	- -	Not recovered
122.12 A	Easy	9900	515	128-25	40.0	- -	- -	Ran preshot time; P.P. only
B				151-25	40.7	- -	- -	Ran preshot time; P.P. only
C				81-25	40.3	- -	- -	Ran preshot time; P.P. only
D				185-50	38.0	- -	- -	Peak pressure record
122.13 A	Fox	11460	595	132-25	30.6 *	- -	- -	P.P. only
B				150-25	30.4 *	- -	- -	Good P-T record
C				137-25	30.0 *	- -	- -	Good P-T record
D				144-25	- -	- -	- -	Not recovered
122.14 A		13396	697	36-15	19.9	- -	- -	P-T record - Drum gage
B				32-15	- -	- -	- -	Stylus left disk
C				40-15	20.7	1.936	2.785	Good P-T reading
D				[illegible]	20.5	- -	- -	Peak pressure record
Q_s				[illegible]	20.0	- -	3.12	Good P-T reading
Q_t				[illegible]	29.2	- -	3.09	Good P-T record
124.01 A	George	14500	754	60-15	17.1	1.327	3.44	Good P-T record
B				48-15	17.2	- -	- -	Ran preshot time; P.P. only
C				56-15	16.2	- -	- -	Peak pressure record
124.02 A		15900	827	24-15	14.1	4.498	3.809	Good P-T record
B				25-15	13.8	4.437	3.802	Good P-T record
124.03 A		15426	802	23-15	15.4	4.310	- -	Good P-T record

* Gages recovered from Operation REDWING

no damping material was used in the pressure inlet holes of the pressure-time gages, the records showed little or no overshoot. Where there were four gages per station, the agreement between them was excellent. At no station did the indicated peak overpressure vary more than ± 3 percent about the mean average.

3.4.3 Presentation of Data

The results of Shot 4 are listed in Table 3.4. The curve for peak overpressure versus distance plotted in Figure 3.4 consists of a mean average of the values obtained at each station.

The values of the peak overpressure have been reduced to 1 KT at sea level and plotted in Figure 4.1 along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.5 SHOT 5

3.5.1 Recovery

On Shot 5 only three of the nine gages used to instrument the Dog Complex were recovered. Due to the excessive washing the islands

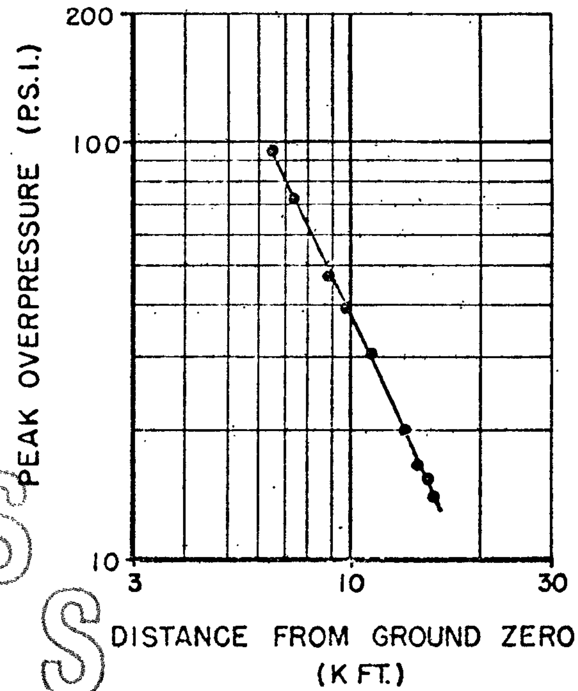

Figure 3.4 Ground surface pressure versus distance, Shot 4.

received from Shot 4, only three stations were left with usable mounts. Since the mounts were protruding from 12 to 18 inches above the original ground surface, only two gages each were installed at Stations 122.10 and 122.12. It was feared that these stations would be washed, and the postshot recovery proved these fears to be justified. Of the five gages installed at Station 122.14, two were lost and three were recovered. The stations instrumented and distances are listed in Table 3.5.

3.5.2 Records

Two of the three records recovered produced good pressure versus time traces. The third gage ran; but the stylus apparently left the recording disk during the decay, so that pressure versus time was lost.

3.5.3 Results

The results from Shot 5 are summed up in Figure 3.5, where one peak overpressure point is plotted. The yield is 13.5 MT, so a curve

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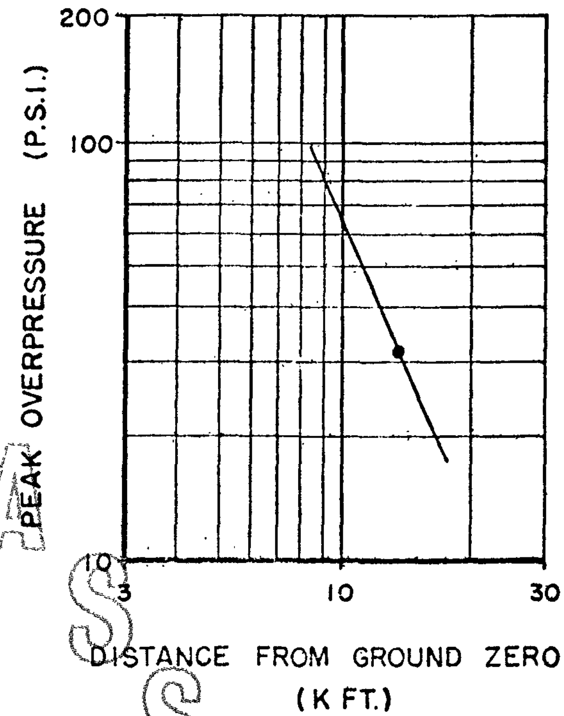

Figure 3.5 Ground surface pressure versus distance, Shot 5.

TABLE 3.5 - Results of Shot 5

Station and Position	Site	Distance from GZ (ft) Actual	A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
122.10 A	Dog	7789	326	273-150	- -	- -	- -	Not recovered
B				190-50	- -	- -	- -	Not recovered
122.12 A	Easy	10192	427	225-50	- -	- -	- -	Not recovered
B				98-25	- -	- -	- -	Not recovered
122.14 A	Fox	13663	572	118-25	31.7	2.18	3.60	Good P-T record
B				139-25	- -	- -	- -	Not recovered
C				17-15	33.2	- -	- -	P.P. only
D				55-15	31.7	1.82	3.87	Good P-T record
q_s				104-25	- -	- -	- -	Not recovered
q_t				155-25	- -	- -	- -	Not recovered

parallel to the pressure versus distance curve of this yield is plotted in Figure 3.5.

The values of the peak overpressure have been reduced to 1 KT

[redacted]

at sea level and plotted in Figure 4.1, along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.6 SHOT 6

3.6.1 Recovery

On Shot 6 there were 32 pressure-time and 10 "q" gages used to instrument 14 stations. All gages except one "q" gage on Gene (Station 124.16) and one "q" gage on Helen (Station 124.19) were recovered. The gage mounts at these stations failed, apparently due

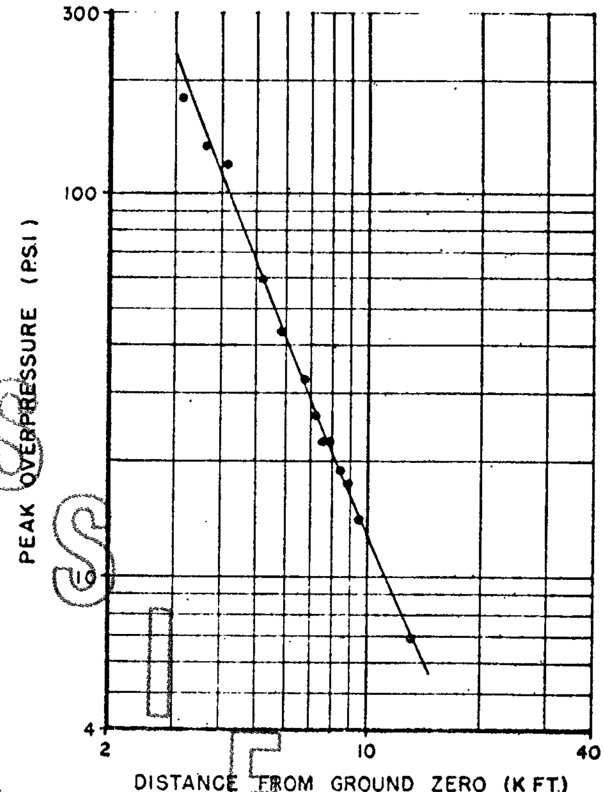

Figure 3.6 Ground surface pressure versus distance, Shot 6.

to high overpressure and excessive washing of the islands. The stations instrumented and distances are listed in Table 3.6.

3.6.2 Records

Of the 48 records recovered, all but 7 produced readable data. Good pressure-time records, free of acceleration effects were obtained at overpressure values up to 150 psi. Dynamic pressure measurements were obtained, with a maximum recorded value of 197 psi. Good agreement was obtained between peak overpressures at any one station.

3.6.3 Presentation of Data

The results of Shot 6 are listed in Table 3.6. The curve of peak overpressure versus distance plotted in Figure 3.6 consists of a

[redacted]

TABLE 3.6 - Results of Shot 6

Station and Position	Site	Distance from GZ (ft) Actual	A-Scaled	Capsule and Range	Peak Overpressure (psi)	Arrival Time (sec)	Positive Duration (sec)	Remarks
124.16 A	Gene	3200	268	345-400	235	- -	- -	Questionable P-T
B				344-400	130	- -	- -	Questionable record
C				317-200	175	- -	- -	Questionable P-T started with shock
q_s				331-400	- -	- -	- -	Not recovered
q_t				352-400	- -	- -	- -	Not recovered
124.17 A	Gene	3700	309	318-200	130	- -	- -	Fair P-T
B				347-400	- -	- -	- -	No apparent record
C				240-150	138	- -	- -	Fair P-T
124.18 A	Gene	4200	351	242-150	135	- -	- -	Questionable P-T
B				303-150	100	- -	- -	Questionable P-T started with shock
C				244-150	124	- -	- -	Gage did not run, P.P. only
q_s				279-150	122	- -	- -	Fair P.P.
q_t				339-400	319	- -	- -	Fair P.P.
124.19 A	Helen	5200	435	239-150	- -	- -	- -	No apparent record
B				233-50	58	.538	1.55	Good P-T
C				196-50	61	- -	- -	Stylus broke, Questionable P.P.
124.20 A	Helen	5900	493	209-50	36	- -	- -	P.P. only
B				214-50	51	- -	- -	P.P. only
q_s				243-150	- -	- -	- -	Not recovered
q_t				270-150	- -	- -	- -	Not recovered
124.21 A	Irene	6744	564	216-50	31	- -	.88	Incomplete P-T
B				77-25	34.5	1.88	1.71	Good P-T
q_s				201-50	32.5	2.41	- -	Good P-T
q_t				235-50	56	- -	- -	Good P-T
124.22 A	Irene	7234	605	202-50	26	1.29	- -	Good P-T
B				100-25	26.5	1.19	1.98	Good P-T
124.23 A	Irene	7600	635	119-25	22.5	- -	- -	Ran preshot time; P.P. only
B				102-25	- -	- -	- -	Drum gage; record broken
q_s				222-50	23.5	- -	3.22	Good P-T
q_t				197-50	37.6	- -	3.24	Good P-T
124.24 A	Irene	7900	660	156-25	22.2	- -	- -	Did not run, questionable P.P.
B				116-25	23.0	- -	1.99	Good P-T
q_s				226-50	22.4	- -	2.20	Good P-T
q_t				200-50	34.5	- -	2.15	Good P-T
124.25 A	Irene	8501	711	159-25	18.8	- -	2.11	Good P-T
B				138-25	19.2	- -	- -	Started after shock wave, P.P. only
Cq_s				204-50	19.0	- -	3.06	Good P-T
q_t				205-50	27.8	- -	3.05	Good P-T
Dq_s				78-25	--	- -	- -	Stylus did not record
q_t				76-25	26.6	- -	- -	Good P-T
124.26 A	Irene	8992	752	148-25	- -	- -	- -	Gage did not run; no record
B				131-25	17.4	- -	- -	Ran preshot time; good P.P.
q_s				147-25	16.8	- -	4.22	Good P-T
q_t				105-25	23.7	- -	4.23	Good P-T
124.27 A	Irene	9584	801	179-50	- -	- -	- -	Stylus left disk, no record
B				1-15	14.0	- -	- -	Ran preshot time, P.P. only
q_s				26-15	- -	- -	- -	Stylus did not record
q_t				22-15	19.2	- -	- -	Good P-T
124.28 A	Belle	13089	1094	62-25	8.3	4.46	2.50	Good P-T
B				16-15	7.5	4.44	3.37	Good P-T
X H	Elmer	113752	9510	5-1	0.300	- -	- -	Gage mounted face-on to blast, fair P-T
V				10-1	0.277	- -	8.34	Gage mounted side-on to blast, good P-T

[redacted]

mean average of the values obtained at each station.

The values of the peak overpressure have been reduced to 1 KT at sea level and plotted in Figure 4.1, along with the reduced values of succeeding shots and a standard 1.6-KT free-air curve.

3.7 DYNAMIC PRESSURE MEASUREMENTS

During the present series of tests, a gage developed at Ballistic Research Laboratories was used to measure dynamic pressures. A detailed description of the gage, its operation, and method of calibration is presented in Appendix B. The definition of dynamic pressure in this case is the difference between the stagnation overpressure and the static or side-on pressure. A photographic enlargement of the initial portion of a typical record is shown in Figure 3.8. The data from all shots on which dynamic pressures were measured are listed in Table 3.7. The values of dynamic pressures versus distance from Shot 6 are plotted in Figure 3.7. The peak dynamic pressure values corrected for the compressibility factor have been reduced to 1 KT at sea level and plotted in Figure 4.5, along with a theoretical dynamic pressure curve based on a yield of 1.6 KT in free air.

TABLE 3.7 - Dynamic Pressures

Shot Number	Station Number	Distance from GZ (ft) Actual	A-Scaled	Static Overpressure (psi)	Total Overpressure (psi)	Dynamic* Pressure (psi)	Corrected Dynamic Pressure (psi)
3	180.09	6,500	1,280	7.48	8.60	1.12	1.10
	333.02	8,205	1,616	4.43	5.20	0.77	0.76
	124.15	8,200	1,615	3.80	4.27	0.47	0.47
	124.14	8,800	1,734	3.25	3.75	0.50	0.50
4	122.14	13,396	697	20.0	29.2	9.20	8.50
6	124.18	[illegible]	351	122	319	197	135.0
	124.21	[illegible]	564	32.5	56.0	23.5	20.3
	124.23	7,600	635	23.5	37.6	14.1	12.8
	124.24	7,900	660	22.4	34.5	12.1	11.1
	124.25	8,501	711	19.0	27.8	8.8	8.2
	124.26	8,992	752	16.8	23.7	6.9	6.5

*NOTE: The application of the pressure scaling factor produced no significant changes in these pressure values. Consequently the corrected dynamic pressure values have been plotted against the appropriate reduced distances in Figure 4.5.

3.8 GROUND SURFACE ACCELERATION MEASUREMENTS

During the past year research has been carried on by the Explosion Kinetics Branch of the Ballistic Research Laboratories to develop a simple accurate means of measuring ground acceleration. It was found feasible during UPSHOT-KNOTHOLE to use the coated glass disk of the BRL mechanical pressure-time gage for recording accelerations. With proper orientation the accelerameter elements will record

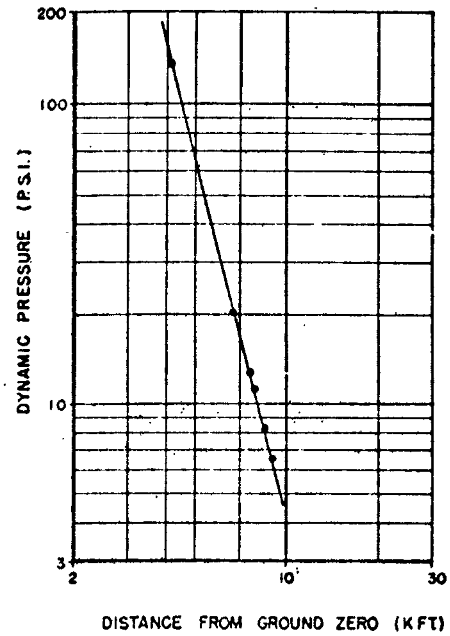

Figure 3.7 Dynamic pressure versus distance, Shot 6.

both vertical and horizontal acceleration versus time. The details of construction, method of recording, results and calibration are presented in Appendix E.

3.9 LOW PRESSURE GAGE

Satisfactory records were obtained on Site Elmer (on Eniwetok Atoll) from all tests shots fired on Bikini Atoll, except Shot 3 (see Figure 3.16). A record was obtained for Shot 3; however, the amplitude of the pressure wave was extremely small and no attempt was made to read a peak value. In addition, excellent records were obtained from a gage placed on board the USS Curtis on Shots 2 and 3. The records obtained compared favorably with those obtained by the Sandia Corporation's microbarograph instruments. The shapes of the recorded pressure waves, although greatly compressed time-wise, were similar. Photographic enlargements of the initial portion of the record and the complete recording disk for the gage located on Site Elmer on Shot 2 are presented in Figures 3.16 and 3.17. A comparison of four BRL and SC records are presented in Appendix F.

3.10 METHOD OF DATA REDUCTION

3.10.1 Record Reading

All records on Shots 1 through 6 were read with the aid of a Gaertner Toolmakers Microscope. Direct measurements were made from

[redacted]

the recording disk by use of the optical system of the microscope for amplification. Readings of the deflections on the records are usually made to the nearest 1/2 mil or 0.0005 inch, although it is possible to read to 0.0001 inch if necessary. Under ideal conditions, the width of the trace should be 0.2 to 0.3 of a mil. Due to the variation in the thickness of the aluminized coating and the pressure

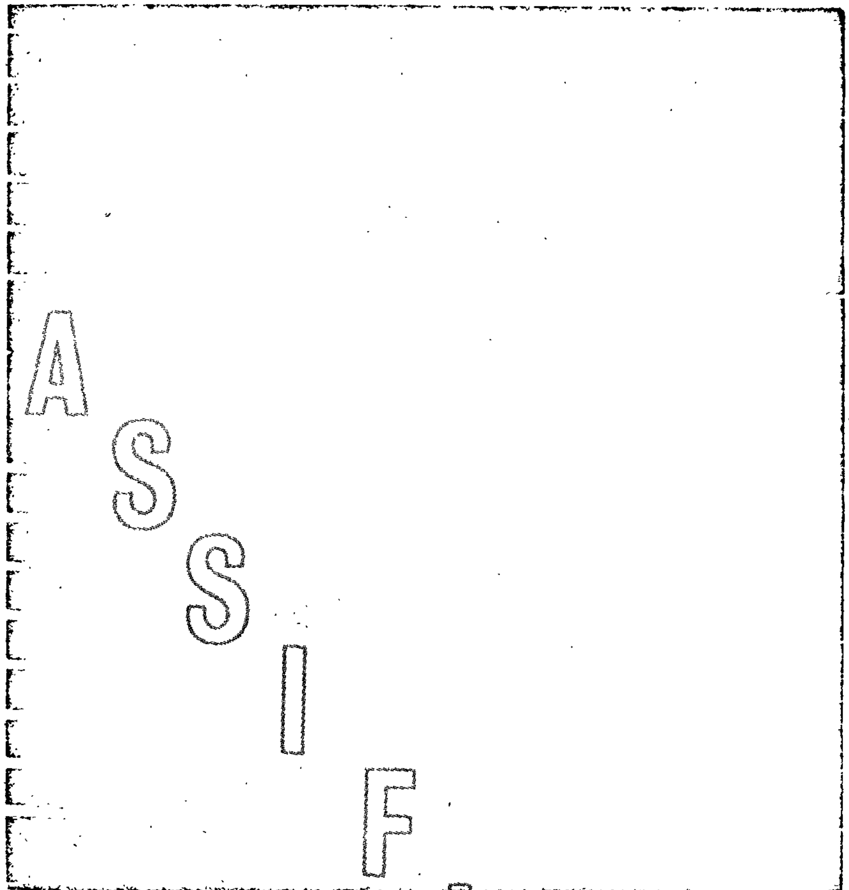

Figure 3.8 Initial portion of static overpressure versus time and total overpressure versus time from the BRL dynamic pressure gage. Each calibration step represents 1 psi. Shot 3, Station 124.15.

of the stylus on the recording disk, ideal conditions were not always obtained.

When the recording is centered on the microscope turntable, it is possible to read time along the record in terms of degrees of rotation. The rate of turn of the recording disk is 3 rpm. This is broken down to 1 revolution per 20 sec or 18° rotation per sec. The

[redacted]

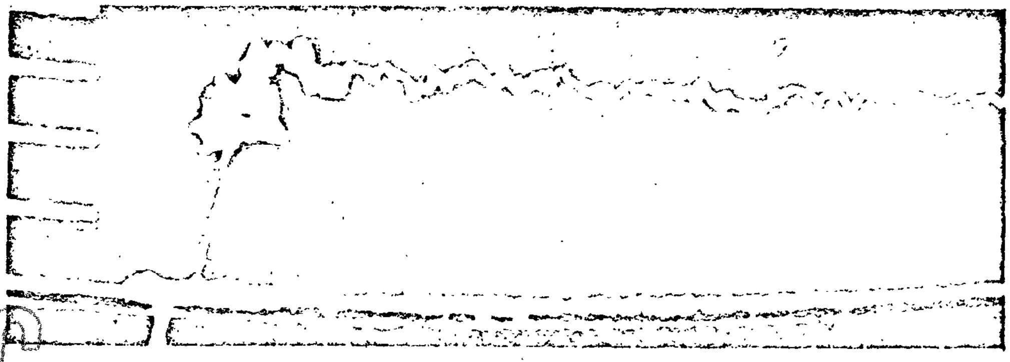

Figure 3.9 Record of pressure versus time, showing high-frequency oscillation due to play in the turntable. Shot 2, Station 123.03. Calibration step: 5 psi.

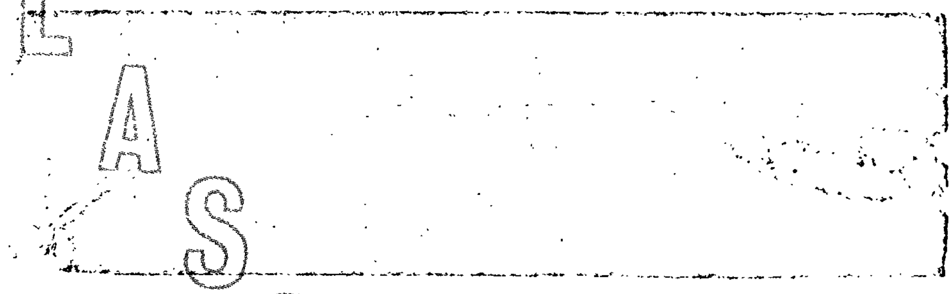

Figure 3.10 Record of pressure versus time, showing a slow rise time and leveling off due to over-damping and clogging of the [illegible] inlet hole. Shot 2, Station 123.03. [illegible] step: 5 psi.

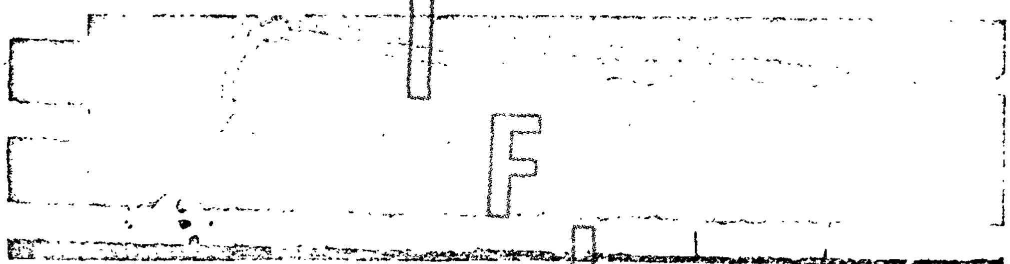

Figure 3.11 Record of pressure versus time, showing a 100 magnification because of the small deflection due to low yield. Shot 3, Station 122.19, Calibration step: 5 psi.

angular rotation of the microscope can be read to minutes. Therefore the reading equipment is capable of resolving time to 1 msec. By this method arrival time and durations of positive and negative phases are determined.

3.10.2 Record Photography

For ease in reading the records, a projection attachment was

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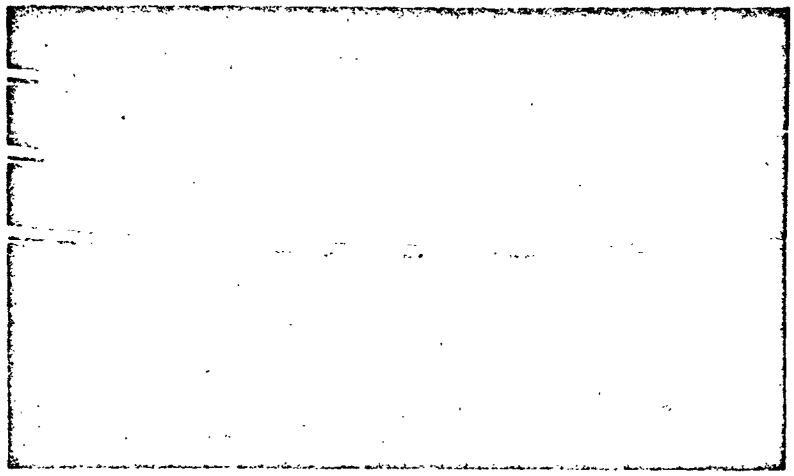

Figure 3.12 Initial portion of a pressure versus time record, showing the improvement after modification. Shot 4, Station 124.02. Calibration Step: 7.5 psi

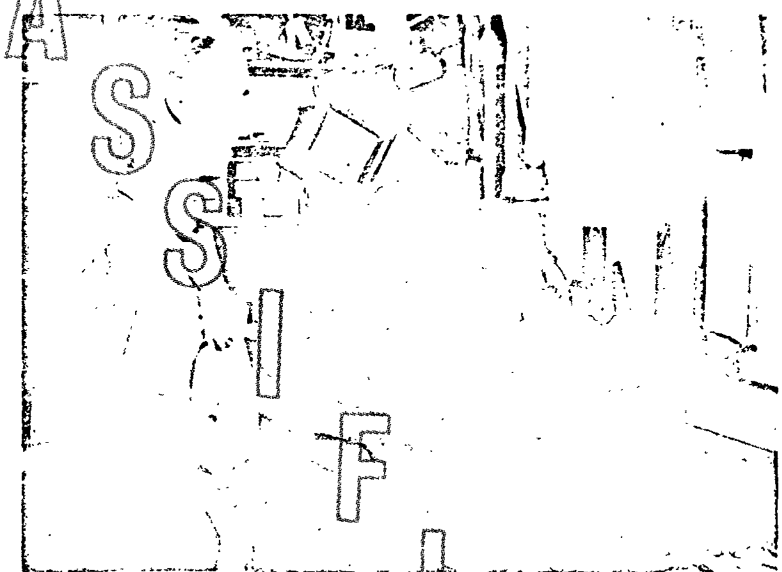

Figure 3.13 Microscope with photographic attachment and projector.

used to project the image on a ground-glass viewer. The film holder and ground glass screen from a 4 x 5 camera was modified to fit the projection attachment (see Figure 3.13). In this manner photographs were taken on a 4 x 5 film for detail study and analysis. The calibration steps on the enlarged records were put on by means of multiple exposures. All of the record except the base line was blanked off and exposed. After exposure the record holder was moved the proper distance in mils to represent a particular pressure from the calibration

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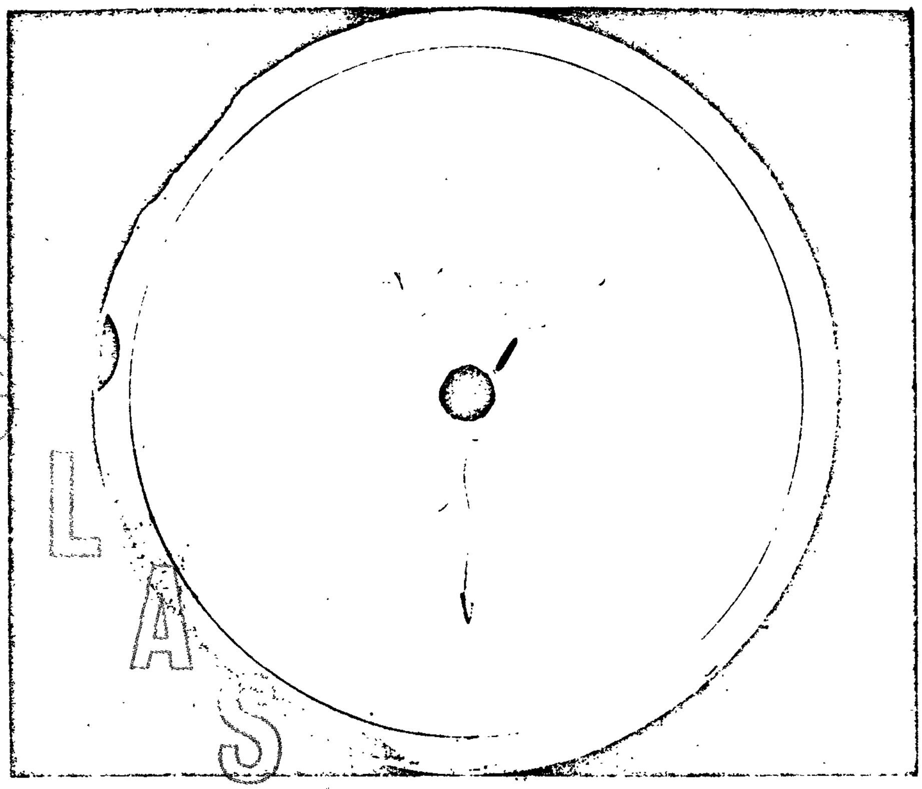

Figure 3.14 Complete record as made from a photographic enlarger. Shot 4, Station 122.05.

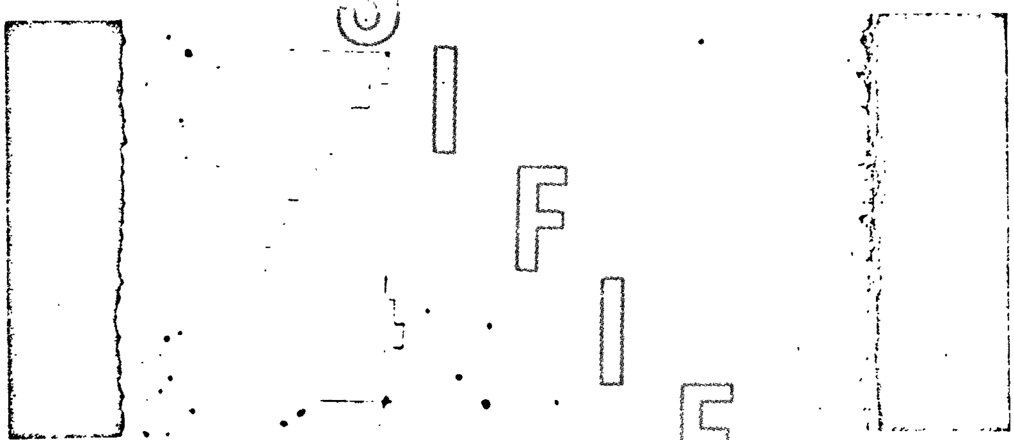

Figure 3.15 Peak pressure record with [illegible] calibration steps. Shot 4, Station [illegible].

curve. The base line was then exposed and the process repeated until the desired number of steps was obtained. Photographic enlargements of the initial portion of the pressure time record along with the calibration steps are presented in Figures 3.8 through 3.12. Prints of the complete trace were made of each record using an enlarger and

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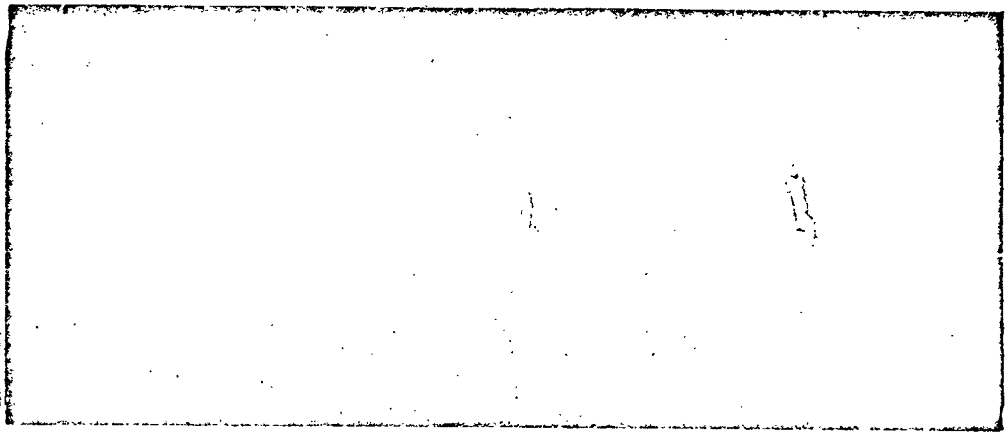

Figure 3.16 Enlargement of initial part of pressure time curve obtained from a VLP gage located on Site Elmer, Shot 2.

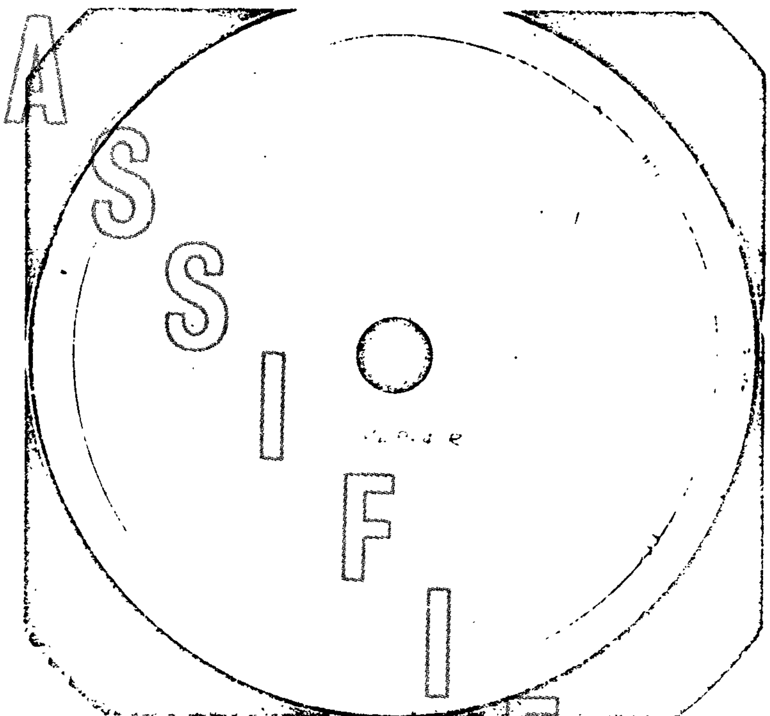

Figure 3.17 Complete record disk obtained from a VLP gage located on Site Elmer, Shot 2.

projecting on sensitive paper. Photographs are shown of a pressure-time curve in Figure 3.14 and a peak-pressure record in Figure 3.15. Calibration steps were put on the peak-pressure records before each shot and can be seen in Figure 3.15.

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Chapter 4
DISCUSSION

4.1 GENERAL

4.1.1 Comments on Measurements

The program of measurements undertaken for CASTLE was concluded with a reasonable amount of success. Overpressure data were obtained covering the range from 0.3 to 250 psi. Pressure-time records were obtained from each shot. The positive-phase durations are tabulated for each shot and presented in Chapter 3. The values obtained are not consistent, but a continuing program of investigation has been initiated at BRL to insure better time measurements on all future tests.

The peak overpressures obtained agree with measurements made by the Sandia Corporation (Reference 4). In most cases, the variation was considerably less than ± 10 percent. A comparison of values is presented in Table 4.1.

4.1.2 Pressure Attenuation on Shot 3

Shot 3 produced the only anomalous results. On this shot two distinct curves of pressure versus distance were obtained with a deviation of at least 20 percent. As seen in Figure 2.5, two blast lines were instrumented approximately 180° apart. One blast line covered the Tare Complex, while the other extended along Site UNCLE. The pressures obtained along the Tare Complex were as much as 20 percent lower than the pressures at comparable distances on Uncle. Strong evidence has been obtained which indicates that the shot was fired during a heavy localized rain storm on the Tare Complex. Photographs taken by TU-9 during the shot from a station on Site Oboe show a general diffuse light but no fireball. Further evidence was found in some aerial radar photographs taken by Project 6.1 before and after shot time. These photographs show that either a cloud with a high moisture content or a rain storm was centered over the Tare Complex. The Tare Complex is completely obscured, whereas Sites Uncle, Victor, and William are clearly discernible (See Figures 4.2 and 4.3). Still further indication of the unsettled atmospheric conditions is the apparent attenuation of the thermal energy along the Tare Complex. The flash initiators of the pressure-time gages functioned satisfactorily on Site Uncle out to and including the [illegible] at a distance of 9380 feet from ground zero. On the [illegible] the 6300-foot station was the furtherest out station at which the initiators functioned.

Because of the low yield, Shot 3 was a disappointment to many

TABLE 4.1 - Comparison of BRL and SC Data

Shot	Distance from GZ (ft)	BRL Peak Overpressure (psi)	Sandia Peak Overpressure (psi)
3	5,600	8.1 *	8.0
	7,400	4.6 *	4.8
	8,800	3.5 *	3.4
	10,900	2.36 *	2.2
	12,200	1.8 *	2.0
	14,300	1.3 **	1.7
	17,000	1.02 **	.92
4	11,460	30.3 ***	27.4
	13,310		20.0
	13,396	20.4 ***	
	14,500	16.8 ***	16.6
	15,900	13.9 **	14.0
6	4,180		75.0
	4,200	120.0 ***	
	5,200	59.5 **	
	5,270		50.0
	5,900	43.5 **	43.0
	7,620	22.5 *	23.0
	9,580	14.0 *	13.6

* Single gage reading
** Average of two gages
*** Average of three gages

of the agencies attempting to measure various parameters. It was, nevertheless, an ideal experiment for checking present-day theory on the attenuation of blast pressure to be expected from various yields due to the liquid water content present in the air. The known parameters are the peak overpressure versus distance along a clear blast line and rain blast line and the yield associated with the clear blast line. The unknown quantity being the amount of liquid water present in the air as the shock wave passed through it. Liquid water content in the air is expressed in terms of grams per cubic meter and the symbol "c" is used to designate it in the equation to follow.

The approach used by Hartman, Penny and Gauvin (References 5, 6, and 7) is based on the amount of energy it takes to completely evaporate the water present in the air, out to a given radius. The radius of complete evaporation is defined in Reference 5 as that distance at which a shock having travelled in the usual fashion in clear air will completely evaporate a drop of water placed in its path. The radius of complete evaporation does not mean the radius within which all water would be evaporated if the charge were fired in rain or fog. That radius is less than R_1, since in rain or fog the shock appears to come from a progressively smaller charge as it moves out evaporating the water that is engulfed. An empirical equa-

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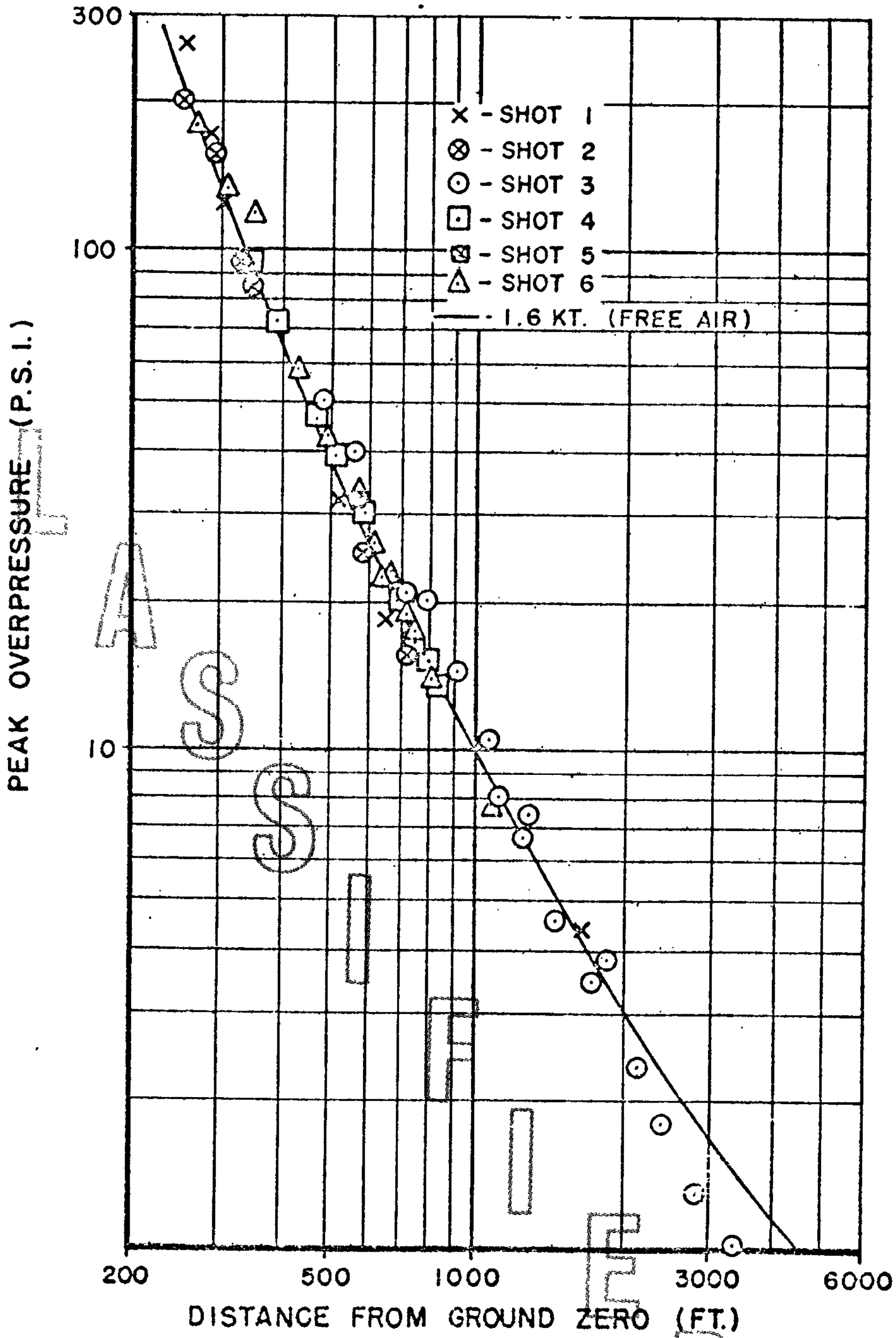

Figure 4.1 Composite ground surface pressure versus distance (scaled to 1 KT at sea level).

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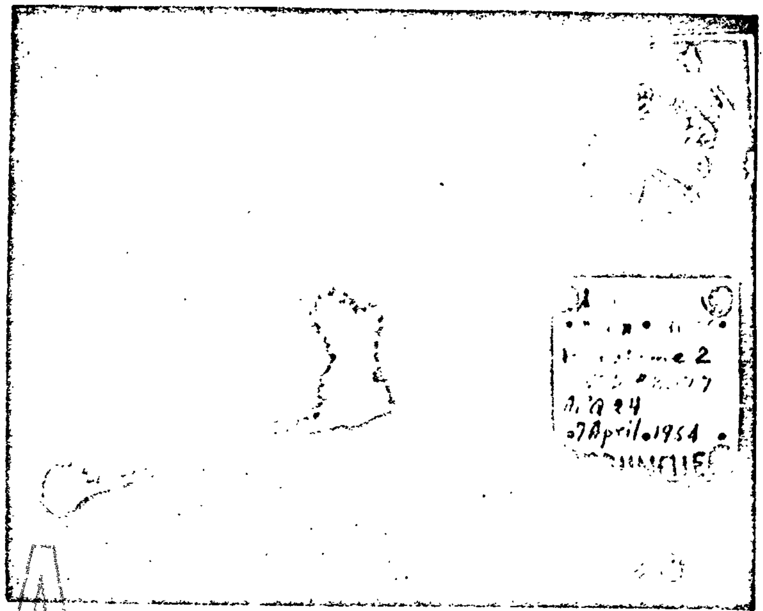

Figure 4.2 Radar photograph of the Shot 3 test area just before zero time. Clouded area apparently indicates precipitation over the Tare Complex.

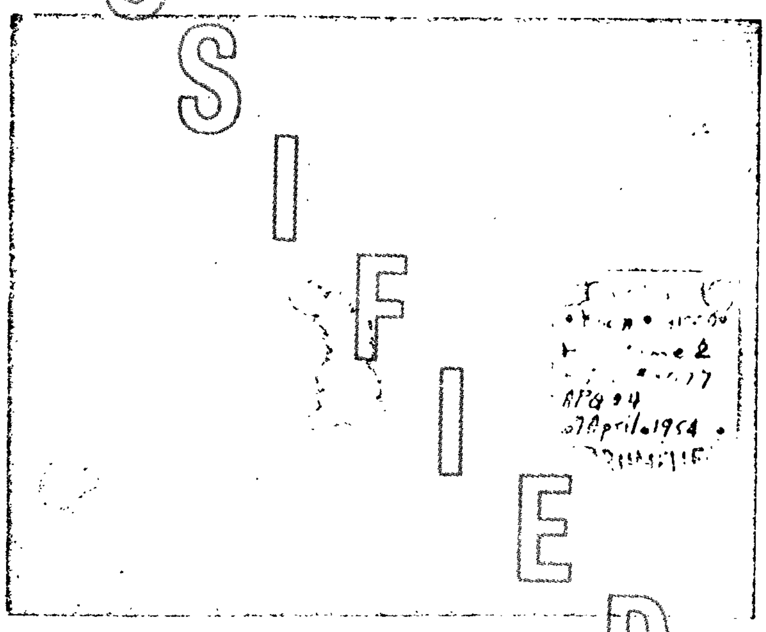

Figure 4.3 Radar photograph of the Shot 3 test area just after zero time. Clouded area apparently indicates precipitation over the Tare Complex.

[redacted]

tion is presented (Reference 5) where the radius of complete evaporation for rain is dependent only on charge weight.

$$R_1 = 5.1\ (W^{1/3})^{1.11}\text{ft} \qquad (4.1)$$

Where: W is in lbs of TNT

The apparent yield obtained by BRL on the clear blast line was 150 Kt. This was established by use of the composite free air pressure curve and assuming the 2W theory to be valid. By the same method the apparent yield on the Tare Complex was 110 Kt. If 0.50 is used as the TNT blast equivalent energy and then the 2W theory applied for a surface burst, it gives an equivalent TNT yield of 150 Kt or 3.0×10^8 lbs of TNT. From Hartman's report (Reference 5) he predicts that a charge weight ZW fired in clear weather gives the same shock energy at a distance R that a charge of weight W gives when fired in the presence of rain or fog.

Therefore, $Z < 1$ and is a function of R and W. The equation presented for Z is as follows:

$$Z = \left[1 - 1.70 \times 10^{-4}\ \frac{cR^{11/3}}{W^{11/9}}\right]^{9/11} \qquad (4.2)$$

For calculating the attenuation of pressure due to rain or fog the usual procedure would be to choose a W and c and calculate Z versus R. On this shot the value of W along a clear line is known and the values of pressure (Pr) along a rain blast line and the values of pressure (P) along a clear line are known. Therefore, the following procedure was used to determine the amount of liquid water content (c) present along the rain blast line.

First various values of c were substituted in Equation 4.2 and solved for Z. When a value of Z was determined for a particular c it was inserted in the following emperical equacion and checked for the actual value of Pr obtained from the record. This equation holds rather closely between 4 and 20 psi based on TNT considerations.

$$Pr = PZ^{0.63} \qquad (4.3)$$

In order to find the distance at which a given rain drop will be completely evaporated, substitute $(ZW)^{1/3}$ in Equation 4.1 and determine R_1. If the R used when substituting in Equation 4.2 is $< R_1$, then the value of Pr is valid. If R is $> R_1$ then the assumption is no longer valid because all of the water at that distance has not been evaporated.

A value of $c = 0.9$ gm/m^3 seems to fit the experiment best and it signifies that a rainfall of slightly less than 1 in/hr was falling

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during the shot. A table of values are listed below assuming a $c = 0.9\ gm/m^3$.

TABLE 4.2 - Pressure Attenuation for $c = 0.9\ gm/m^3$

P(psi)	R(ft)	$\left[R^{11/3}\right] \times 10^{14}$	Z	Pr	$(ZW)^{1/3}$	R_1	
38.0	3000	0.06	0.969	37.2	662	6898	$R_1 > R$ Valid
20.5	4000	0.16	0.911	19.4	648	6742	$R_1 > R$ Valid
16.0	4500	0.25	0.862	14.6	637	6605	$R_1 > R$ Valid
12.7	5000	0.36	0.800	11.0	620	6410	$R_1 > R$ Valid
10.5	5500	0.52	0.705	8.4	595	6132	$R_1 > R$ Valid
9.2	5820	0.63	0.65	7.0	580	5900	$R_1 > R$ Valid
8.9	6000	0.71	0.589	6.4	560	5730	$R_1 < R$ Not Valid

It may be assumed that beyond 5800 feet there will be some further evaporation but not complete evaporation and that the shock front will move out in the usual manner or as though it were generated from a charge of (ZW) energy where Z equals approximately 0.65. If it is assumed that there is no further loss in energy due to evaporating moisture then the equation $Pr = PZ^{0.65}$ should hold for distances beyond 5800 feet if Z is held constant. Therefore, $Pr = P0.65^{0.65}$ or $Pr = P0.762$.

TABLE 4.3 - Comparison of Measured and Calculated Pressure Attenuation

Distance(ft)	Clear Line P	Rain Line Pr	Calculated Pr
3000	36.0	37.0	37.2
4000	20.5	17.5	19.4
5000	12.7	10.5	11.0
5820	9.2	7.2	7.0
* 6000	8.9	6.9	6.8
* 7000	6.5	5.15	4.95
* 8000	5.15	4.00	3.92
* 9000	4.2	3.20	3.20
* 10000	3.53	2.64	2.69

* Z is held constant beyond 5820 feet

The above values are plotted in Figure 4.4.

4.1.3 Instrumentation

In general, the gages operated satisfactorily. Some difficulties appeared after Shot 1. The actual yield of this shot far exceeded the preshot prediction. Consequently, most gages were subjected to pressures considerably in excess of the rated maximum pressures. Excessive overstressing and permanent sets obtained in the pressure capsules caused most readings to be in error by ± 15 percent. An examination of the Shot 1 records made it apparent that [illegible] were susceptible to acceleration effects as indicated by a c[illegible] amount of hash and oscillations. Figure 3.9 is a photograph of a typical record

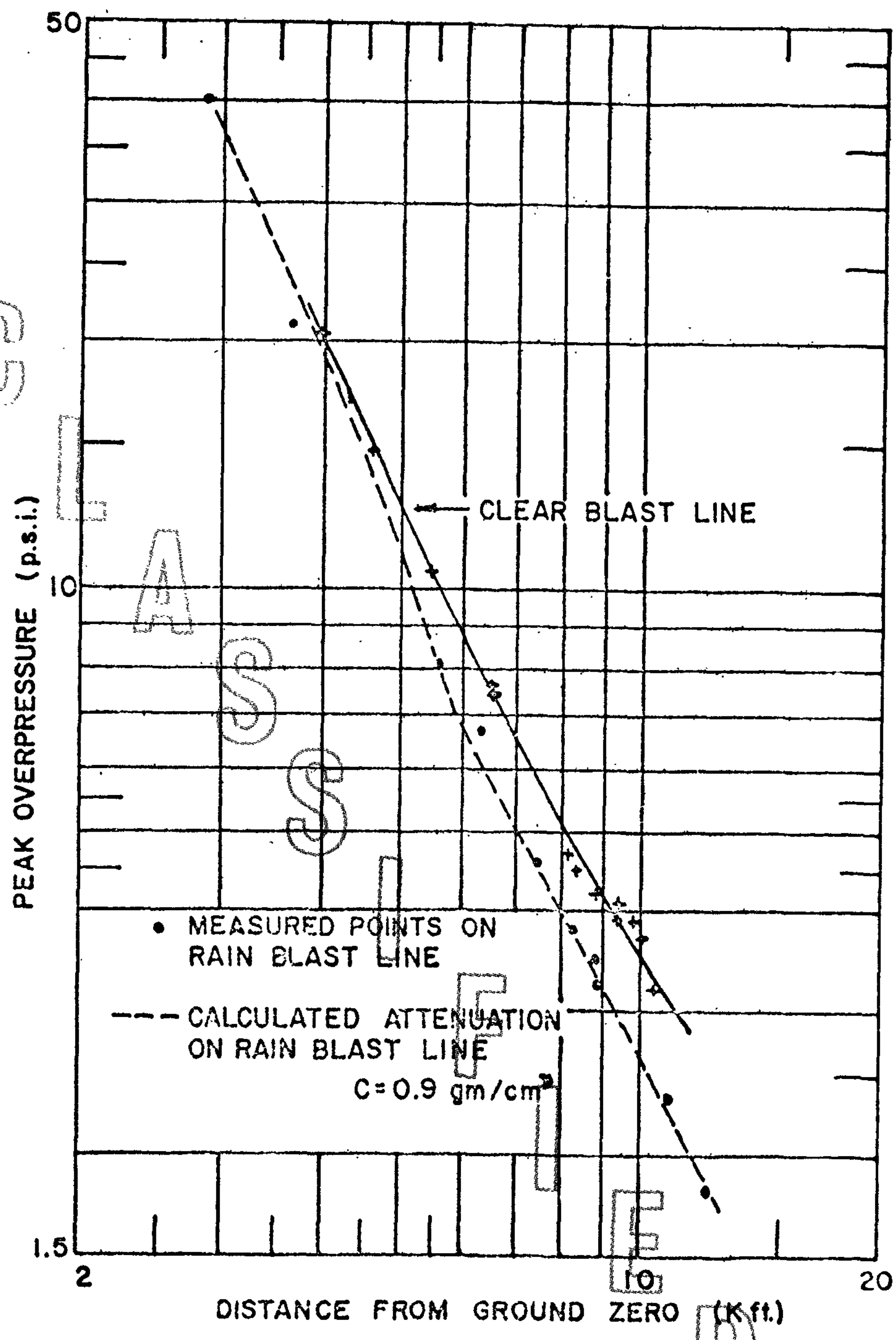

Figure 4.4 Comparison of measured and calculated attenuation of pressure, Shot 3.

[redacted]

showing acceleration effects on the gage as transmitted to the record trace. Certain gage modifications capable of being accomplished in the field (See Appendix B) were incorporated in the gages used in Shots 3 through 6. These gage modifications resulted in relatively "clean" records up to overpressures of 150 psi. Further, a program of postshot gage inspection was initiated (See Appendix D) so that information would be available applicable in explaining defects in gage recordings.

TABLE 4.4 - Summary Data of CASTLE Shots

Characteristic	Symbol	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
Date		1 March	27 March	7 April	26 April	5 May	14 May
Time		0645	0630	0620	0610	0610	0620
Location - Atoll		Bikini	Bikini	Bikini	Bikini	Bikini	Eniwetok
Island		Charlie	Charlie	Tare	Lagoon	Lagoon	Mike Crater
Coordinates	G Z						
North		170,617.16	170,635.05	100,154.50	161,698.83	161,424.43	147,750.00
East		76,163.98	75,950.43	109,799.00	116,800.27	116,688.15	57,790.00
Code Name		Bravo	Romeo	Koon	Union	Yankee	Nectar
Yield (MT)	Wrc	15.0±0.5 (Fire Ball)	11.0±0.5 (Fire Ball)	0.130±0.020	7.0±0.3 (Fire Ball)	13.5±1.0 (Fire Ball)	1.7±0.3 (Fire Ball)
Height of Burst	h	0	0	0	0	0	0
Atmospheric Pressure (mb)	Po	1006.1	1012.4	1009.7	1007.4	1010.8	1006.0
Surface Air Temperature	To	80.0° F	80.0° F	81.0° F	81.0° F	80.8° F	79.9° F
Surface Wind: Direction - Degrees		070°	040°	090°	062°	070°	090°
Speed - Knots		15	10	13	18	20	19
Scale Factors for 1 KT at Sea Level:							
Pressure: $Sp = \frac{1013.3}{Po}$		1.0072	1.0038	1.0037	1.0059	1.0024	1.0073
Distance: $Sd = \left[\frac{1/Sp}{W}\right]^{1/3}$		0.0403	0.0448	0.197	0.0520	0.0419	0.0836
Time: $St = Sd\left[\frac{To + 273}{293}\right]^{1/2}$		0.0407	0.0453	0.199	0.0526	0.0424	0.0845
Where To is in degrees Centigrade, W is in KT							

Ground acceleration records were obtained at a number of stations on Shots 1, 2, 3 and 6. The records appeared to be entirely satisfactory. Details are presented in Appendix E.

4.2 PEAK OVERPRESSURE VERSUS DISTANCE, A-SCALED

The peak pressure-distance data obtained for the CASTLE shots have been reduced to the equivalent of 1 KT (RC) under standard sea-level conditions (14.7 psi atmospheric pressure, 20° C. temperature). The basic characteristics for each shot and the scaling factors are listed in Table 4.4.

The IVY Mike data generally compared favorably with the TUMBLER composite free air pressure versus distance curve for 2 KT as prepared

[redacted]

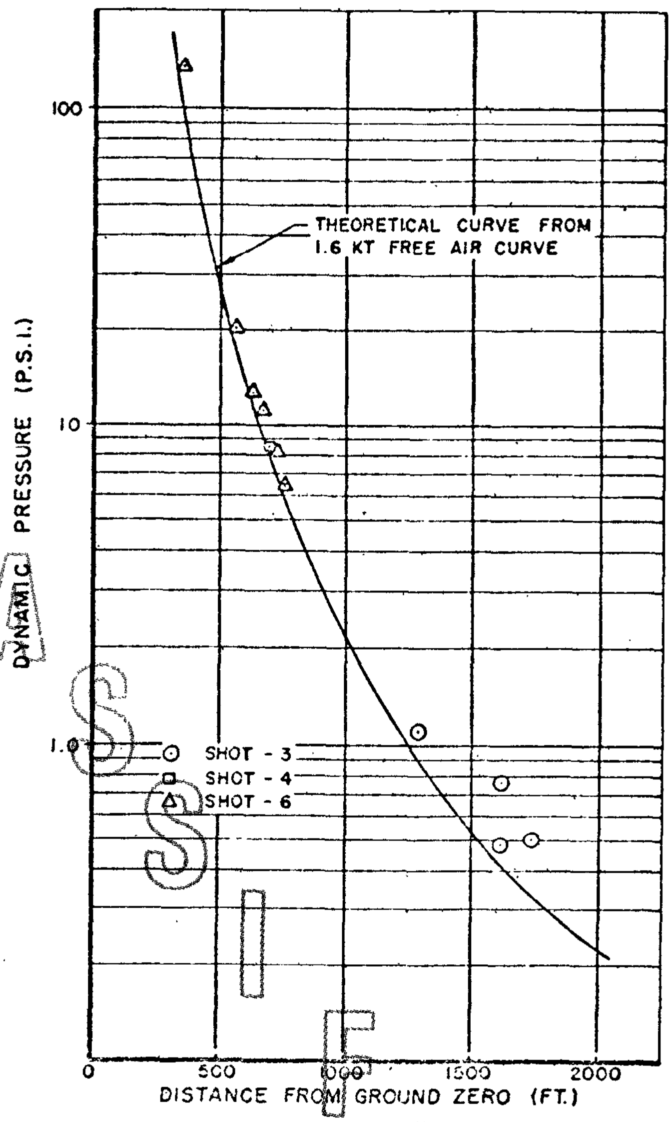

Figure 4.5 Dynamic pressure versus distance, reduced to 1 KT at sea level.

by NOL (Reference 2, 3). A similar comparison has been made with the reduced CASTLE data, and a composite curve of these data (Figure 4.1) are compared with the TUMBLER free air curve scaled to 1.6 KT for pressure levels ranging from 3 to 250 psi.

The overpressures on Shot 1 fall slightly above the 1.6 KT curve at the higher pressures, but these values are from questionable records because of the overstressing of the capsules. The pressures measured along the reef fall below the 1.6 KT curve. From later field experiments it was found that the lower values are a function of the type gage mount used and that the actual values could be as

[redacted]

much as 20 percent higher. This correction would place the data from the two reef stations more nearly on the 1.6 KT curve.

The high overpressures recorded from the land stations on Shot 2 are in good agreement with the 1.6 KT curve while the two reef stations again show lower pressure values than would be indicated by the curve. A correction as mentioned in the previous paragraph would bring these values more in line with the pressure values from other shots at similar scaled distances.

The peak overpressures recorded on Shot 3 fall on both sides of the 1.6 KT curve, but this was expected because a yield value of 130 KT was used in scaling both blast lines. If the values from the blast line on Uncle were scaled from a 150 KT yield and those from Tare Complex scaled from a 110 KT yield the pressure values would fall much closer to the 1.6 KT free air curve.

Shots 4, 5 and 6 are all in good agreement with the 1.6 KT curve. Measurements from these shots were from land stations and the values recorded are felt to be reliable with but one exception - Station 124.18 on Shot 6.

4.3 DYNAMIC PRESSURE

Although the measurement of dynamic pressures was a secondary objective and [illegible] used were in the developmental stage, excellent results were [illegible]. The major effort in these measurements was made on Shots 5 and 6. On these shots extensive instrumentation was used, not only for gage evaluation, but also to obtain data for Project 1.8. All measurements of dynamic pressure were corrected for compressibility and supersonic flow where applicable.

The measured dynamic pressure values and the corrected values for all shots instrumented are listed in Table 3.7. In Figure 4.5 the corrected dynamic pressure versus distance (reduced to 1 KT at sea level) are plotted. The atmospheric pressure was so near standard that the scaling factor amounted to less than 0.5 percent and was not applied. The solid line in Figure 4.5 is a theoretical dynamic pressure curve computed from overpressure values obtained from a 1.6 KT free-air curve using the following equation:

$$q = \frac{2.5\,(P_s)^2}{P_s + 7(P_o)}$$

Where: q = dynamic pressure

P_o = atmospheric pressure

P_s = static overpressure

Although the surface pressure measurements show only a small deviation from a scaled 1.6 KT pressure versus distance curve, the scaled dynamic pressure values plot higher than would be predicted from a 1.6 KT curve of side-on pressure versus distance.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 INSTRUMENTATION

The family of self-recording gages for measurement of blast wave parameters obtained results which in some respects compared favorably with corresponding electronic instrumentation. Peak overpressure measurements agreed very well. Reasonably good agreement was apparent when wave shapes were compared on shots in which the modified gage was used. Even though the field modifications to the pressure time gage alleviated a large portion of the acceleration effects, additional modifications appear to be advisable.

The "q" gage produced excellent results which compared very well with the electronic instrumentation. Continued use of these types of gages on all future tests is strongly recommended.

The scratch-type self-recording accelerometer appears to be capable of producing good results and should be more fully utilized in future tests.

5.2 TEST RESULTS

The validity of the cube root scaling law to scale distances for yields as great as 14.5 MT appears to have been well substantiated.

The dynamic pressures obtained on Shots 3, 4, and 6 are apparently in agreement with theoretical values over a dynamic pressure range 0.43 to 135 psi.

The overpressure attenuation observed on Shot 3 would seem to indicate that a significant reduction in pressures can result when the shock wave passes over an area in which precipitation is occurring.

The overpressures obtained on all shots appear to substantiate an assumption that the overpressures obtained from a surface burst on water and coral atolls are the same as would be obtained from a burst of 1.6 the yield in free air.

The zero intercepts of the height of burst curves as published in TM 23-200 appear to be valid, because of the reasonably good agreement with the results of these shots.

From the records obtained with the self recording gages there was no apparent evidence of the existence of a precursor on any of the test shots.

[redacted]

Appendix A
PERSONNEL

Personnel of the Explosion Kinetics Branch, Terminal Ballistics Laboratory, Ballistic Research Laboratories served in a supervisory capacity in the preparation, field operation and data analysis phases of this project. These personnel were:

J. J. Meszaros, Project Officer
C. N. Kingery, Deputy Project Officer
H. S. Burden, Technical Group Leader.
C. H. Hoover. Technical Group Leader
R. E. Reisler, Technical Group Leader

Certain military personnel were retained at these laboratories after Operation UPSHOT-KNOTHOLE to assist on Operation CASTLE. The primary assignments for these personnel are indicated below:

<u>Officers:</u>

D. A. Kahle, USA, Associate Technical Group Leader
J. N. Varnell USA, Associate Technical Group Leader
E. Starr USAF, Associate Technical Group Leader

<u>Enlisted Personnel:</u>

F. L. Cornwell, USAF, Technical Group
E. O. Engle USAF, Technical Group
D. C. Freeswick, USAF, Accelerometers
J. E. Gurgel, USAF, Technical Group
W. E. Lynch, USAF, Technical Group
M. M. Silver, USAF, Technical Group
R. N. Tucker, USAF, "C" and "q" gage
R. C. Wagner, USAF, "q" gage
W. L. King, USA, Logistics
R. A. Rejent. USA, Technical Group
R. J. Mudd, USA, Technical Group

[redacted]

Appendix B
INSTRUMENTATION DESIGN

B.1 GENERAL

B.1.1 Pressure-sensing Element

The basic component, common to all the types of pressure gages used by the project, during CASTLE, except the very low pressure gage, was a capsule consisting of two concentrically convoluted diaphragms, nested together to reduce volume, and silver soldered around their periphery. These pressure capsules or elements were essentially identical to those incorporated into gages used by Project 3.30 during UPSHOT-KNOTHOLE, (Reference 1). Briefly, during operation, air enters the element through a small pressure inlet hole causing expansion of the diaphragms. A light spring stylus soldered to the center of one diaphragm transmits this motion and produces a scratch on a coated glass recording blank. The amplitude of this scratch is proportional to the movement of the diaphragm. A sapphire pointed phonograph needle soldered to the stylus arm is used to insure a fine scratch. The basic characteristics of these elements are as follows:

Diaphragm Material--------------------------NiSpanC
Deflection (at Rated Pressure)
  Maximum---------------------------------0.060 inches
  Minimum---------------------------------0.020 inches
Linearity----------------------------------± 0.5 percent
Hysteresis---------------------------------± 0.5 percent
Natural Frequency (undamped) 1400-2000 cps
Rise Time----------------------------------3 msec or less
Operating range----0-150 percent of max rated pressure
Pressure Inlet Hole (diam.) 0.152 inches
Diameter-----------Variable (dependent on pressure range)

The very low pressure gage uses a single phosphor-bronze, convuluted diaphragm, 5 3/4 inches in diameter.

The diaphragm forms one side of the gage case. Any pressure differential existing between the inside and outside of the gage causes the diaphragm to deflect. This deflection is transmitted to and scratched on a coated glass recording blank by a stylus soldered to the center of the diaphragm. The stylus point is the same as used on the basic pressure elements.

The various pressure elements used are shown in Figure C.1.

B.1.2 Recording Blanks

The recording medium of the scratch type self-recording gages was pyrex glass. The various sizes and shapes are shown in Figure C.2.

[redacted]

An aluminized surface coating was used on the blanks instead of the machinist bluing used previously, (Reference 1). This type of surface was less susceptible to damage from water, was more even, rugged and cleaner. A very five sharp edged scratch was produced by the stylus needle. Under ideal conditions with a uniform coating the scratch width was less than 0.3 mil. Unfortunately, the thickness and quality of the coating varied greatly and though extreme care was used in the selection of blanks it was not always possible to do more than approach these ideal conditions.

B.2 PRESSURE-TIME GAGE (STANDARD)

B.2.1 General

The pressure-time gage was the basic instrument used during CASTLE to obtain the measurements required by the objectives of Project 1.2b. Several pilot models were field tested by BRL during UPSHOT-KNOTHOLE (Reference 1). The basic ideas and the test results were combined and a final design prepared. A quantity of these gages were fabricated and shipped directly to the Pacific Proving Grounds. Lack of time precluded any preliminary tests on the gage. The gages were either photo-initiated or thermal initiated and used a small D. C. motor to drive the recording disk. A delay switch was incorporated which would start operating at zero time and stop the recording at any preset time up to 1-1/2 minutes. The entire unit was encased in a 12 inch length of 5-inch pipe. A 3-inch pipe cap was welded to the bottom of the pipe to give an auxiliary mounting system. The gage assembled to a 3-inch pipe mount is shown in Figure C.16. An adaptor ring, with 6-inch internal pipe threads was bolted on the standard 6-inch pipe mount and the gage placed inside the mount and bolted to the adaptor (see Figure C.[illegible]). In order to insure quick recovery, three methods were provided: (1) the gage with adaptor ring attached could be unscrewed from the mount, (2) the gage could be unbolted from the adaptor ring and the entire gage lifted from the mount, and (3) the top plate and entire gage mechanism could be unbolted from the flange of the gage case and removed, leaving the case still in place inside the mount.

B.2.2 Recording System

The recording blank consisted of an aluminized coated glass disk 3 1/2 inches in diameter. The disk was mounted on a turntable which was mounted perpendicular to the plane of the pressure capsule. The standard pressure capsule was assembled to the face plate of the gage with the stylus in position against the recording disk.

The drive motor was an A. W. Haydon Co. type 5600 series chronometrically governed, 6 volt D. C. motor. A Signal Corps type BA 210/V battery provided the power to the motor. Motor specifications indicated a speed variation of 1 percent or less would occur if the motor were subjected to vibrations of 5-300 cps with 10 g maximum acceleration. The various major components of the gage are illustrated in Figures C.3 and C.4.

The recording speed selected was 3 rpm which in almost every case insured that the full pressure-time phenomena was recorded on a single

[redacted]

revolution of the record disk. The base line was retraced every 20 sec making a maximum of 4 1/2 revolutions if the full recording time was used. The turntable speed at the stylus point was 0.5 in./sec.

B.2.3 Initiation Systems

These gages could be initiated either thermally or by means of a photo electric cell (see Figures C.3 and C.4). The standard method was the thermal initiation system. A spring loaded plunger was held in place by two brass shims soldered together with an alloy having a melting point of approximately 175° F. The thermal energy of the detonation melted the alloy breaking the link and releasing the plunger. The plunger actuated a switch which completed the motor drive circuit and started the recording mechanism.

The phototube initiating system was easily assembled. Requiring the removal of the plunger and the addition of a latching relay inside the gage case. The phototube (Type 917) actuated a strobtron (Type 631-P1) which in turn caused the latching relay to close completing the motor drive circuit. The photo initiation was used very little to due to ~~its~~ susceptibility to moisture, causing premature initiation.

B.2.4 Field Modifications

The excessive detrimental effects of acceleration on the gage records as obtained on Shots 1 and 2, indicate that, if usable pressure-time records were going to be obtained immediate modifications would be required. Much of the machine work on gage components, though commercially acceptable, was not of the precision required to insure proper operation under conditions of high acceleration.

The following modifications were made on a number of gages used for Shot 3, and all the gages used in Shots 4, 5 and 6: (1) The stylus arm was shortened to decrease the moment arm of the stylus point. (2) A number of adjustable felt and rubber tipped friction brakes were machined and assembled beneath the turntable. By adjusting this brake the backlash of the turntable was dampened. (3) Additional set screws were provided to hold the turntable more solidly on its shaft. (4) The turntable and motor coupling shaft bushings were replaced with new bushings. The new bushings were machined more accurately and lengthened to provide more bearing surface to prevent wobble. (5) The turntable coupling shafts were replaced by precisely machined shafts having a good sliding fit in coupling shaft bushing.

These modifications apparently almost completely alleviated the acceleration effects. It is felt, however, that many more modifications should be made on these gages prior to use in any future operation.

B.3 DRUM TYPE PRESSURE-TIME GAGE

B.3.1 General

The drum type pressure-time gage was designed to be a self-recording scratch gage incorporating the feature of a recording blank whose base line was not retraced after the first revolution.

The recording blank was an aluminized glass cylinder with a diameter of 3.15 inches and height of 1 inch. An aluminized coating was applied to the outside surface (see Figure C.2). The cylinder was held in a drum-like assembly mounted on a threaded shaft. Through a set of gears, a 6 volt D.C. chronometrally governed motor drove the drum assembly along its shaft. The drum rotated at 6 rpm and advanced 0.025 inches per turn. The standard pressure elements were used in the gage. The recording drum moved past the pressure element stylus point at a speed of approximately 1 in./sec. and a helical base line was generated. Figure C.6 shows a view of the gage without its case. In addition to the pressure element, two accelerometer elements could be installed in the gage on post provided for them. Dry batteries supplied power to the initiation circuit and motor, the instrument being completely self-contained.

The gage was fitted with a rubber sealing gasket and encased in a short section of 5-inch pipe. A pipe cap welded to the bottom of

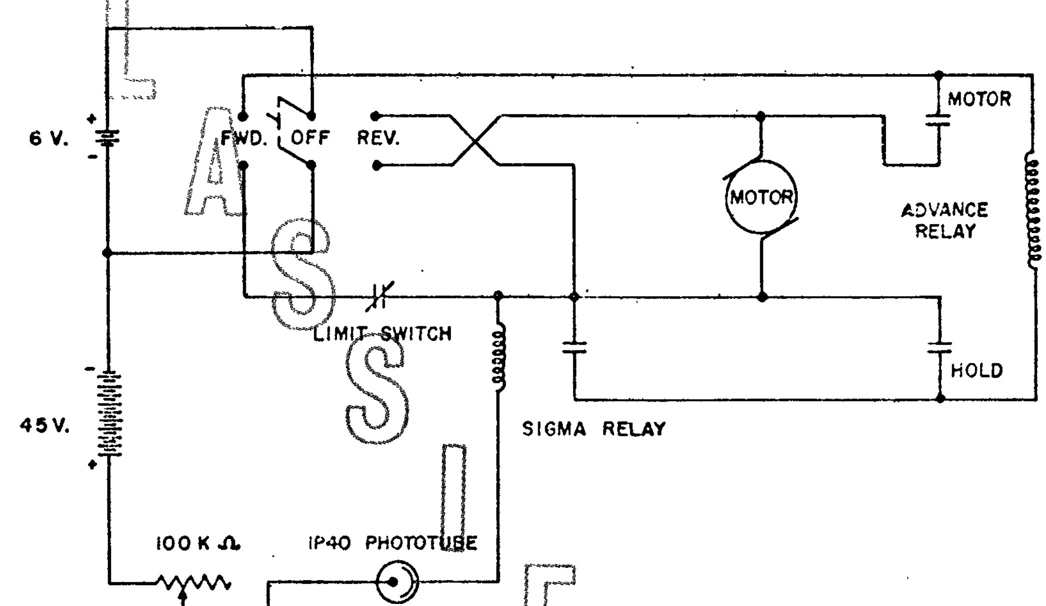

Figure B.1 Drum gage schematic diagram.

the case sealed it and allowed the gage to be screwed onto a 3-inch pipe if that method of installation was desired. A steel mounting-ring was provided for installing the gage in the regular 6-inch pipe mount.

B.3.2 Initiation

The drum gage was started by a photoelectric circuit (see Figure B.1 for Drum Gage Schematic Diagram). This circuit was designed so that the incident light from the detonation would permit enough current to flow through the coil of the very sensitive Sigma relay to cause its contacts to close. The Sigma contacts closing energized the advance relay and power was supplied to the constant-speed motor. The 1P40 phototube was mounted on the outside of the gage on connectors attached to a short piece of rubber covered wire. A packing gland was provided in the gage case to insure a pressure tight seal for the initiation cable.

The potentiometer was set so that bright sunlight would not trigger the circuit. In most instances, a piece of exposed film was wrapped around the phototube and a cardboard collimator wrapped the tube to further insure that premature triggering would not take place. After the gage was started, the fact that the phototube might be blown away was of no consequence as the hold contact of the advance relay kept the motor circuit intact. The gage ran until the advancing drum depressed the limit switch. This limit switch was usually adjusted to allow the drum nine revolutions or 1 1/2 minutes running time.

B.4 PRESSURE-TIME GAGE, CLOCK TYPE

The clock type pressure-time gage or "C" gage (see Figure C.7) is essentially the same as the pressure-time gage as used in UPSHOT-KNOTHOLE by Project 3.30 (see Reference 1). It records pressure-time by the action of a pressure sensing capsule on a rotating aluminized glass disk. The disk is rotated at 5 rpm by a 6 volt vibrating-reed motor. Initiation is accomplished by a 24 hour clock which depresses a micro-switch. The initiation system was modified to permit setting of start time up to approximately 96 hours prior to shot time by using two switches connected in series. One consists of a set of contacts geared to the arm shaft of the clock so the contacts close every 96 hours. The other is a microswitch closed by the pointer arm of the clock every 24 hours. The former provides a coarse time adjustment; the latter permits a fine time adjustment (± 2 min) and also limits the running time of the gage to approximately 20 minutes. Both the depressor arm and geared contacts are adjustable so the starting time can be readily set for any value from 0 to 95 1/2 hours in advance.

B.5 PEAK PRESSURE GAGE

The peak pressure gage was extremely simple in construction consisting essentially of six major components:

(1) Standard Pressure Capsule.

(2) Gage Plate. A 1/2 inch thick steel plate, 8 1/2 inches in diameter. A pressure inlet hole 0.152 inches in diameter was drilled through the plate slightly off center. The pressure capsule was mounted on the plate with capsule inlet hole in line with the hole through the plate.

(3) Glass Record Blank. The blank was a rectangular piece of glass coated with an aluminized surface (see Figure C.2). The blank dimensions were 1/2 inch wide and 1 inch long, in operation the blank was cemented to the slide.

(4) Slide and Slide Holder. This unit provided mounting for the glass blank and was mounted beside the capsule on the gage plate. The holder was so mounted that the capsule stylus point rested on the glass blank. A screw adjustment was provided to permit the moving of the slide with blank assembled, in a lateral direction past

the stylus point.

(5) Cover. The cover was bolted to the gage plate and was provided with 2 1/2 inch diameter pipe threads to permit auxiliary mounting.

(6) Adaptor Ring. An adaptor ring was provided which bolted to the gage plate and was provided with 6 inch internal threads for mounting on the standard gage mount.

The gage without the cover is shown on Figure C.8. The gage with cover, ready for installation, is shown in Figure C.17.

The gage was calibrated as a complete unit. The calibration pressure steps were placed on the record blank. After calibration the blank was advanced. This movement caused a base line to be scratched on the blank. The cover was then assembled and the gage was ready for installation. Figure 3.15 is a photograph of a record blank showing the calibration steps, the base line, and a typical peak pressure record.

B.6 DYNAMIC PRESSURE GAGE

B.6.1 General

The dynamic pressure gage or "q" gage is a self-initiated, self-recording gage for measuring dynamic pressure. Static pressure and stagnation pressures are recorded on a single aluminized glass disk by the action of two pressure sensing capsules.

The gage (see Figure C.9) is 38 inches long and 3.8 inches in diameter with a hemispherical nose. The static pressure inlet is 12 5/8 inches from the front of the gage and has a diameter of 0.15 inches. The stagnation pressure inlet is 11 inches long with a diameter of 1/4 inch, except for the first half inch from the front which is choked down to 3/16 inch. Two 3-inch female pipe weldolets are welded to the bottom of the gage for mounting. The gage is mounted on two 6 1/2 foot lengths of 3-inch pipe, broken 18 inches below the gage with unions to facilitate recovery. Projecting laterally from the rear of the gage are a phototube and a fusible link for initiation of the gage.

B.6.2 Recording System

The pressure sensitive capsules are mounted with the axis of each 90° apart in a plane through the surface of the recording disk. The capsules are positioned such that the stylii will scratch concentrate traces 1 13/16 inches and 1 5/8 inches in diameter on the aluminized coating on the disk.

Rigid mounting and precision machining are critical in the unit consisting of the recording disk, turntable, mount, and drive motor, (see Figure C.10). Because of a 2-to-1 gear reduction, the turntable is driven at 5 rpm by a 10 rpm chronometric governed 6-volt DC motor, giving a stylus to disk speed of 0.4745 in./sec. for the stagnation element and 0.4254 in./sec. for the static element.

[redacted]

B.6.3 Control System

The control section (see Figure C.11) consisting of the timer switch, the timer motor, the 6-volt motor power supply, the 45-volt photo initiator power supply, and the photo initiator chassis is mounted in the center section of the gage. The components are mounted on spaced metal disks. The unit is held in place in the gage with set screws, and is readily removed through the rear of the gage.

The action of the gage can be initiated either thermally or photo-electrically. The thermal switch and the phototube are located on the rear chamber and are connected to the control section through pressure-sealed connectors. The thermal switch is held displaced by a fusible link which fails at about 155° F. Parallel with the thermal switch is a locking relay which is closed by photoelectric action. A current flow of 400 micro-amps through the tube closes a sensitive relay which in turn closes the locking relay, providing a closed circuit for the drive motor and the electrically parallel timer motor. An adjustable cam on the shaft of the timer motor opens a normal-closed microswitch, stopping both motors after any predetermined running time of from 0 to 30 sec.

B.6.4 Preliminary Shock Tube Tests

In the development of the "q" gage a series of tests were run at the BRL shock tube to determine optimum dimensions and damping of the orifices. These tests covered static pressures from 3 to 30 psi. Various sizes of stagnation pressure orifices, damped and undamped, and varying quantities of damping material in the static and stagnation pressure inlets were tested. From these tests, it was concluded that optimum results would be obtained using a stagnation pressure inlet of 1/4 inch diameter with a 3/16-inch-diameter choke 1/2 inch long in the nose, with 1/4-grain glass wool damping in the static pressure inlet and no damping material in the stagnation pressure inlet.

B.7 CALIBRATION OF PRESSURE ELEMENTS

B.7.1 General

Since all pressure elements, even in a given range, were not identical, a static calibration was required for each. Each scratch calibration in the form of a group of "flags" was recorded on an aluminized glass blank as used in the peak pressure gage.

The element was mounted in a fixture with the recording blank. To insure good response from the diaphragm, each new element was exercised by applying the rated pressure about 10 times. Stylus pressure was adjusted to a pre-established norm and a gasket leakage check made at rated pressure. The pressure and vacuum steps were then applied to the element and the fixture manipulated to produce the flag calibration.

The record was read with a precision micrometer and a calibration curve similar to Figure B.2 was drawn for each element. Calibration of the elements had been made by the manufacturer at 50 and 100 percent of the maximum pressure ratings. It was possible to compare these deflections with the curve obtained by the BRL calibration simulating actual gage mounting of the elements. In most cases good correlation was found. A step calibration, in addition, was made for each peak pressure gage on its shot recording blanks (see Figure 3.15).

The elements were elastic beyond the manufacturer's rating and were calibrated above this rating. The following tabulation gives the

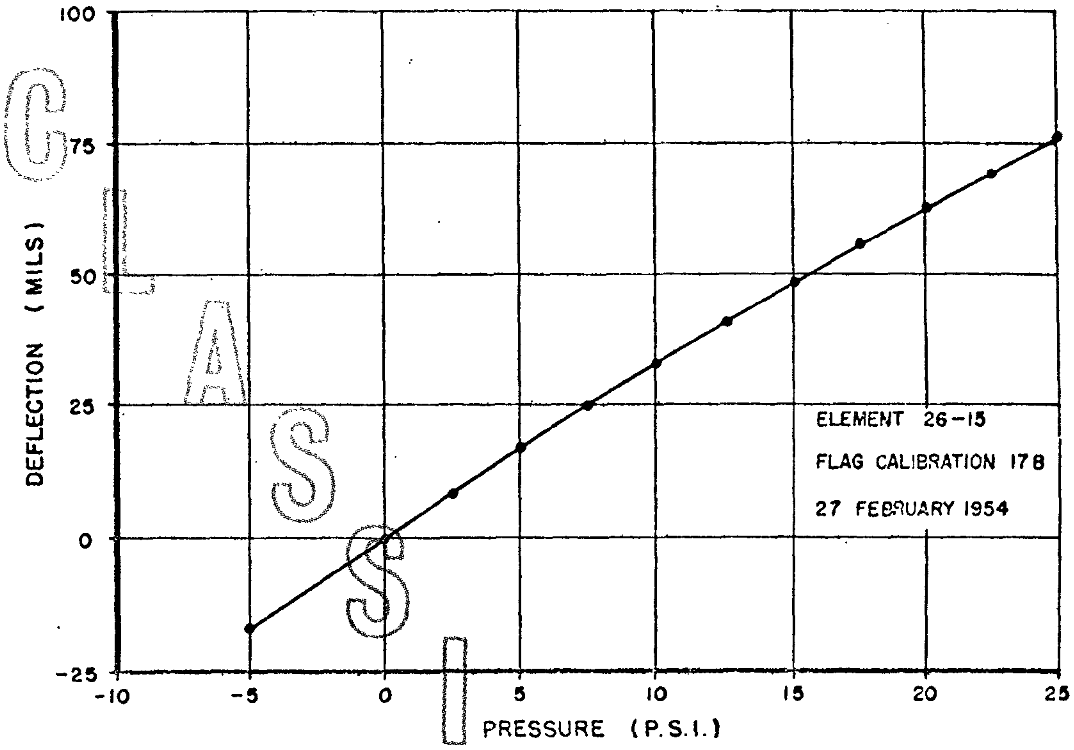

Figure B.2 Typical calibration curve for a pressure element.

maximum pressure to which each range of elements was normally calibrated.

Element Rating (psi)	Maximum Calibration Pressure (psi)
5	10
10	16
15	25
25	40
50	75
100	150
150	190
200	250
400	450

[redacted]

B.7.2 Calibration Equipment

A calibration panel built at BRL was designed to be a complete field unit in itself, only a 110 V A.C. power source being required for field operation of the panel. An aircraft high-pressure air compressor and reservoir and a vacuum pump were part of the calibrator. These and a 28 V selenium power rectifier were mounted on a collapsible stand and connected to the calibration panel.

Flexibility, ease of operation, and safety were prime considerations in the design of the panel. Use of numerous pressure elements in the various shots of the test series made easy operation important. Solenoid valves and a simplified control system were incorporated. Regulators allowed a quick setting of pressure steps. The interlocking relay system and locations of operating switches and buttons promoted the safety required by the high pressures sometimes used in the calibrator. The pneumatic system was built very tight for accuracy in the application of the pressure steps. A front view of the calibration panel is shown in Figure C.15.

Three large, precision gages (20, 100, 500 psi ranges) were used in setting the pressure between 2-500 psi during calibrations. The 20 psi standard was a differential-pressure gage and was utilized for all vacuum measurements. A water manometer was used in conjunction with the calibration panel for the setting of very low pressures.

B.7.3 Special Calibrations

Because some high range elements were overstressed in Shot 1, overstressing calibrations were run on a group of elements of each of these ranges. The elements suffered a slight permanent deformation. Too high an overpressure would cause considerable bulging in the diaphragm and then rupture at the diaphragm seal.

A slight deformation was found to be beneficial; then the element could be recalibrated to the higher pressure without further deforming the element. While the calibration-after-overstressing curve was never a straight line even in the low-pressure region, it was a smooth curve all the way to the overstressing pressure. This overstressing technique extended the range of many of the higher rated elements used in subsequent shots of the test series.

[redacted]

Appendix C
PHOTOGRAPHS

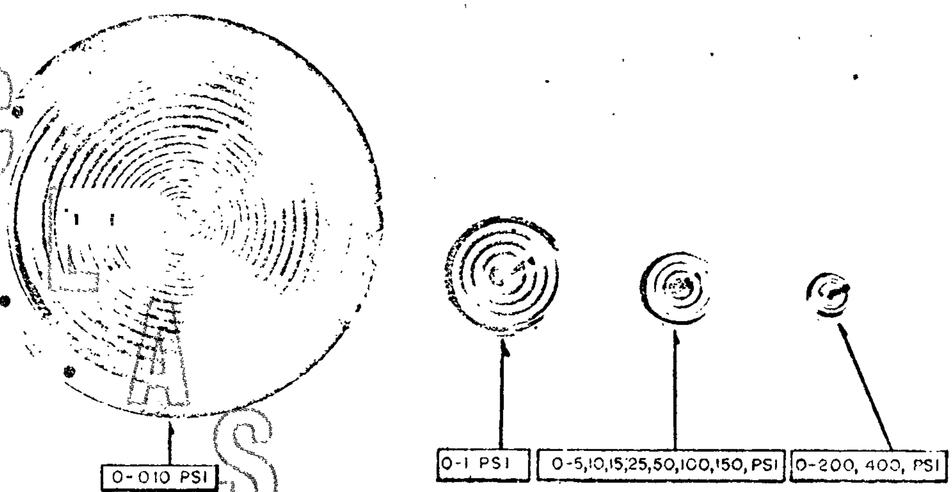

Figure C.1 Pressure-sensing elements.

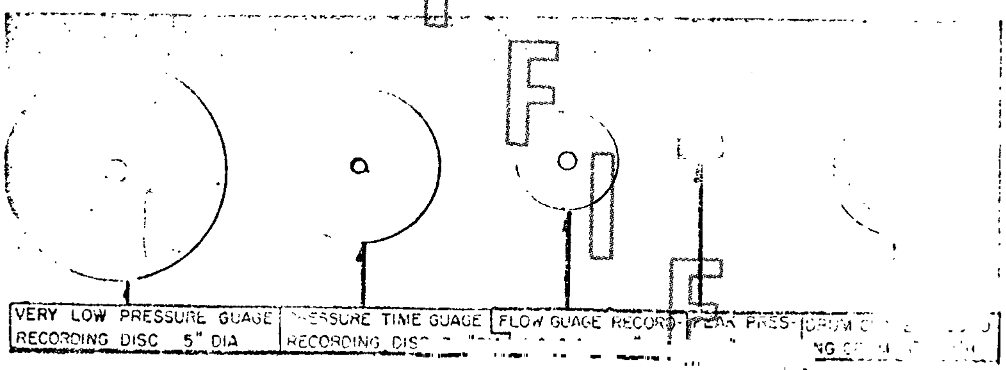

Figure C.2 Various types of recording blanks.

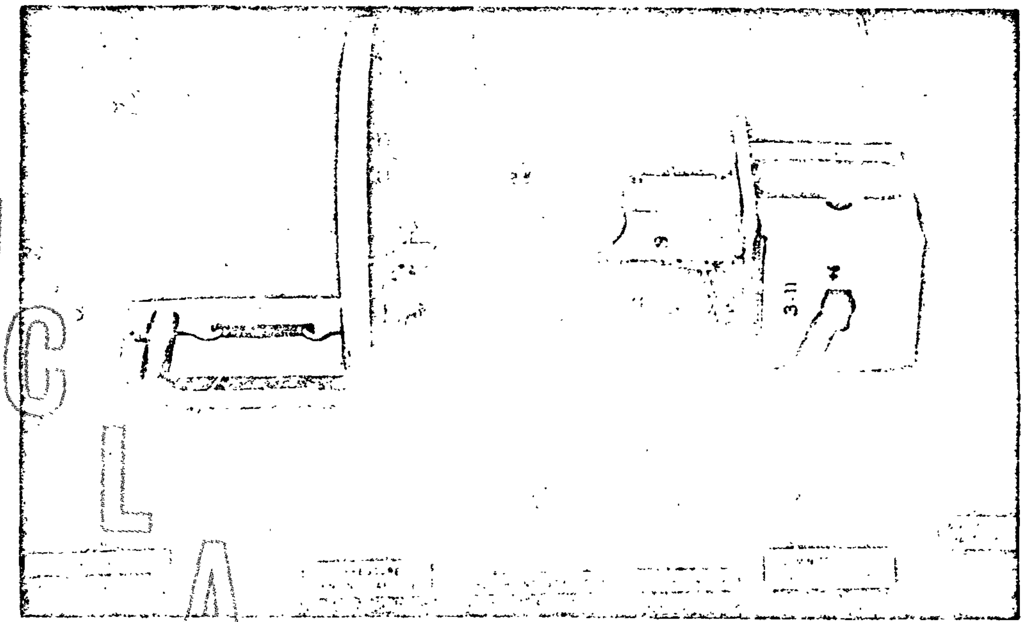

Figure C.3 Pressure-time gage w/o case, thermal initiated.

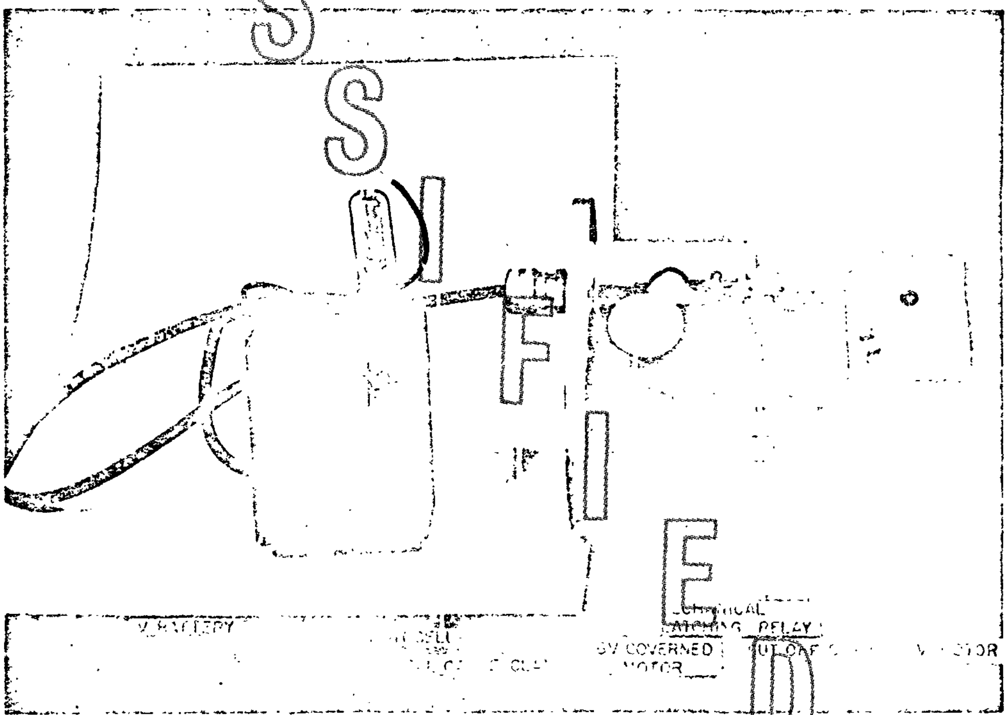

Figure C.4 Pressure-time gage w/o case, photo initiated.

[redacted]

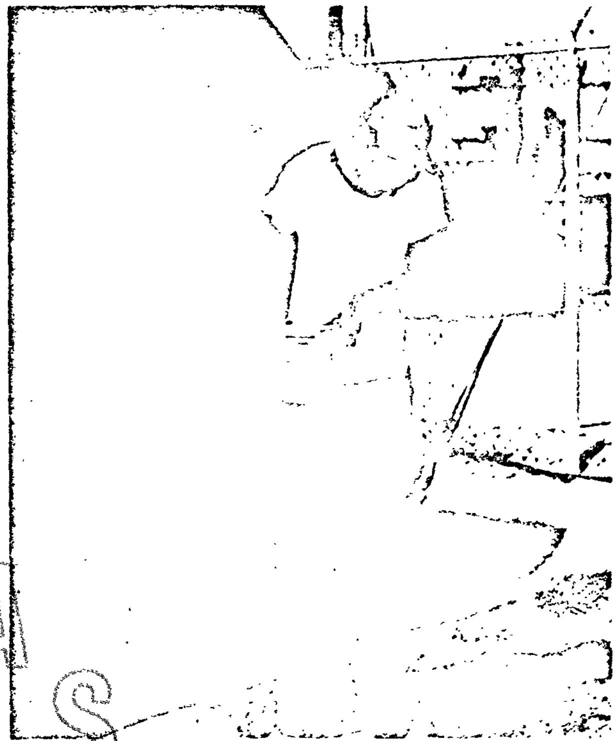

Figure C.5 Installation method-pressure-time gage in 6-inch pipe mount.

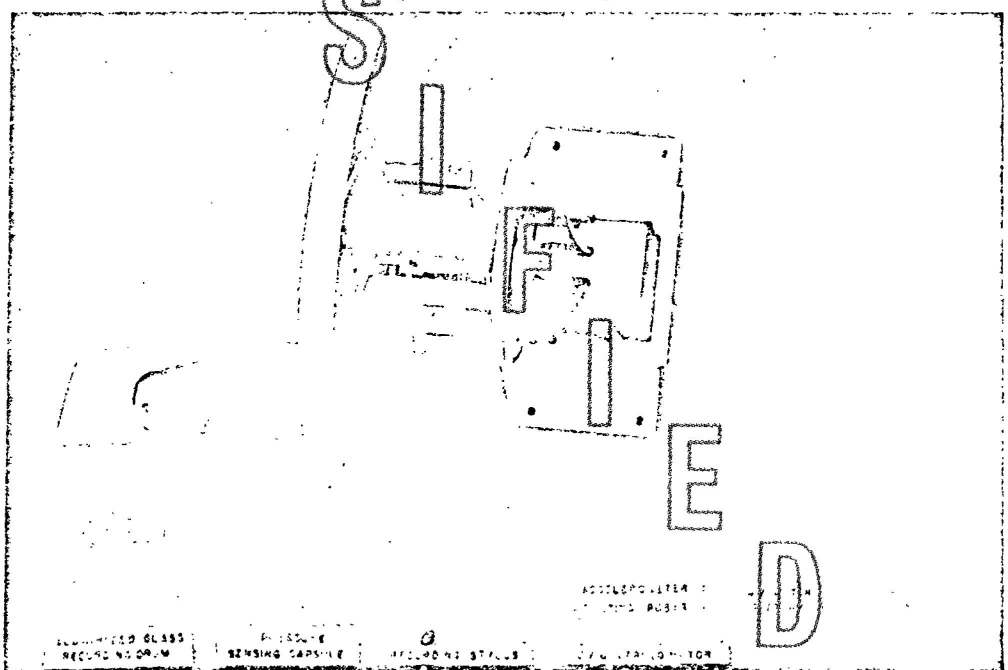

Figure C.6 Drum-type pressure-time gage w/o case.

[redacted]

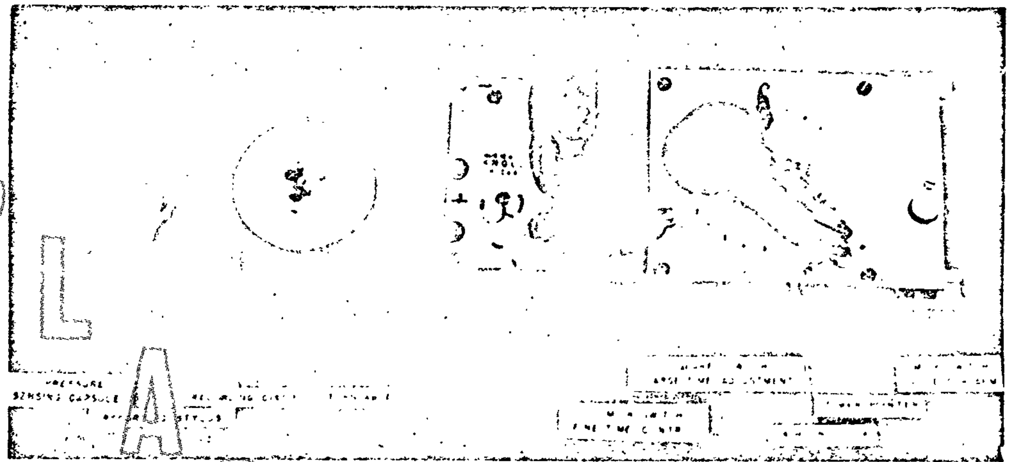

Figure C.7 Clock-type pressure-time gage w/o case.

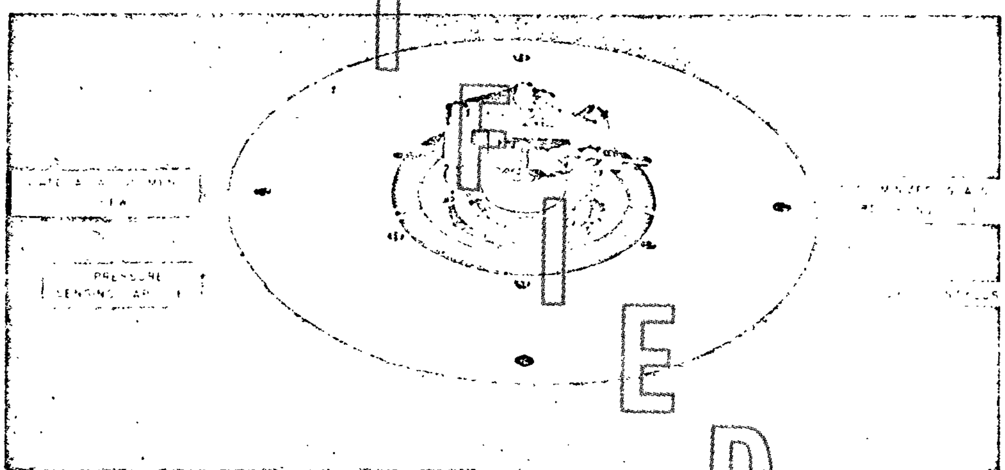

Figure C.8 Peak-pressure gage w/o case.

[redacted]

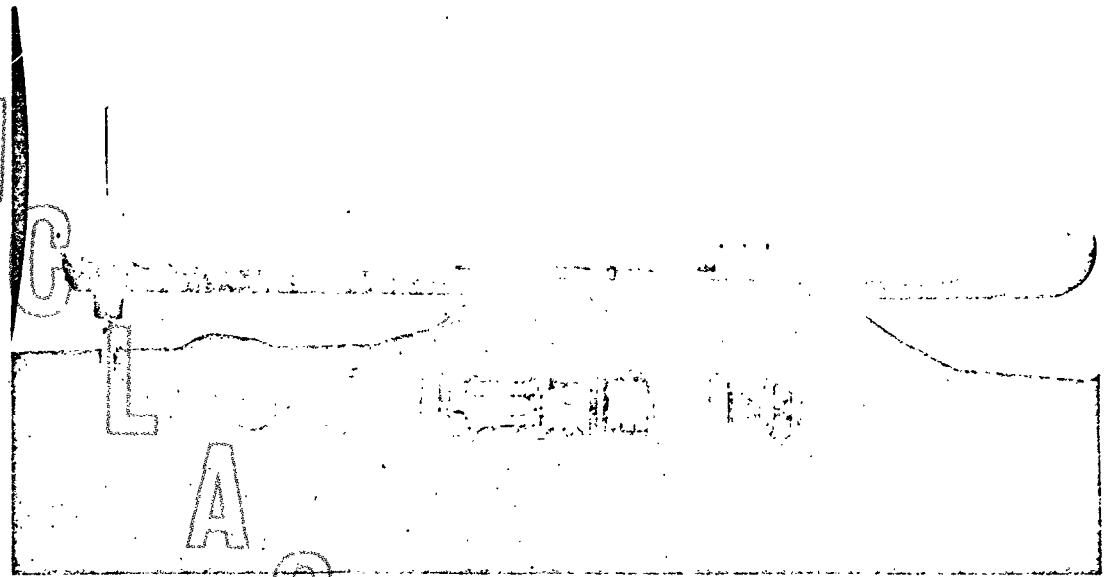

Figure C.9 Dynamic pressure gage.

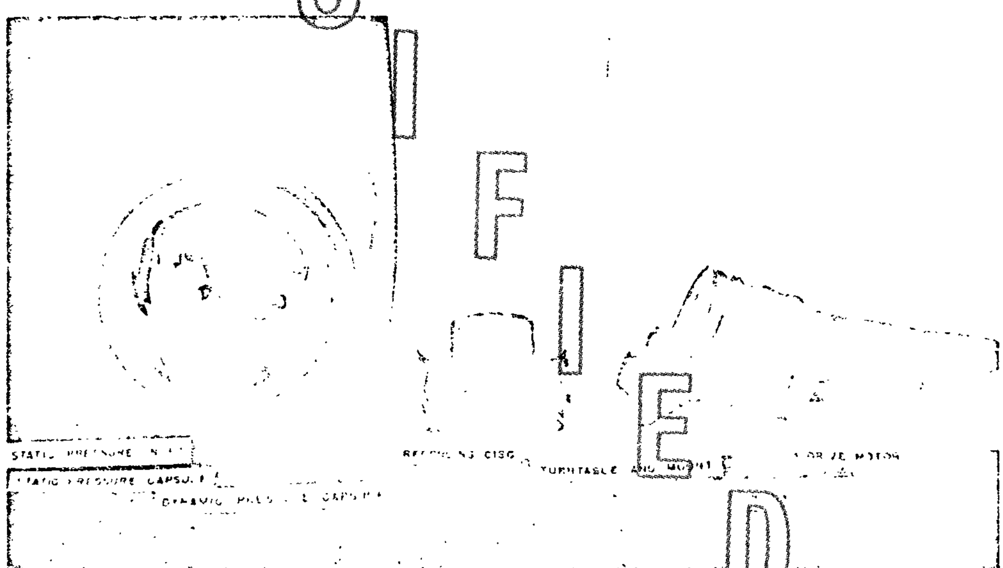

Figure C.10 Nose section, dynamic pressure gage.

[redacted]

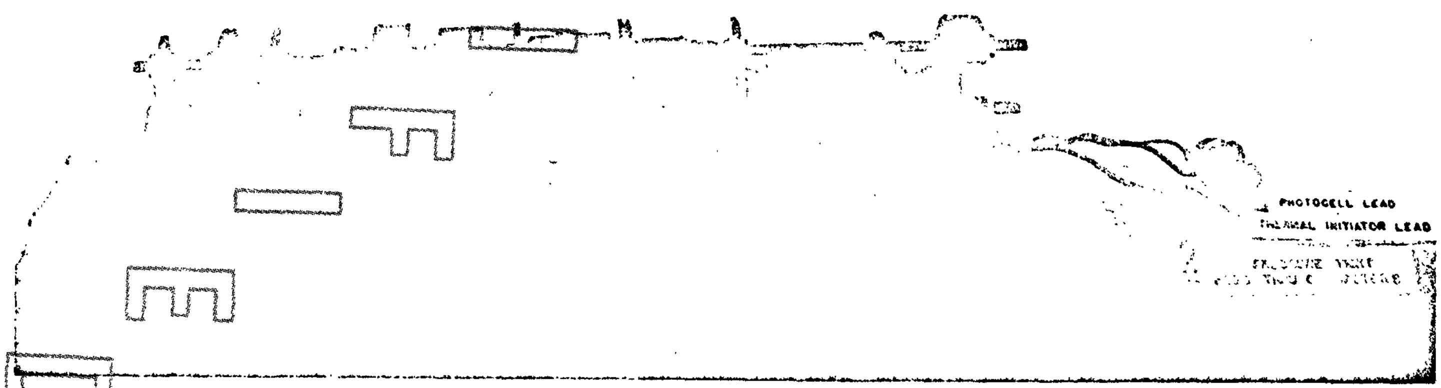

Figure C.11 Control section, dynamic pressure gage.

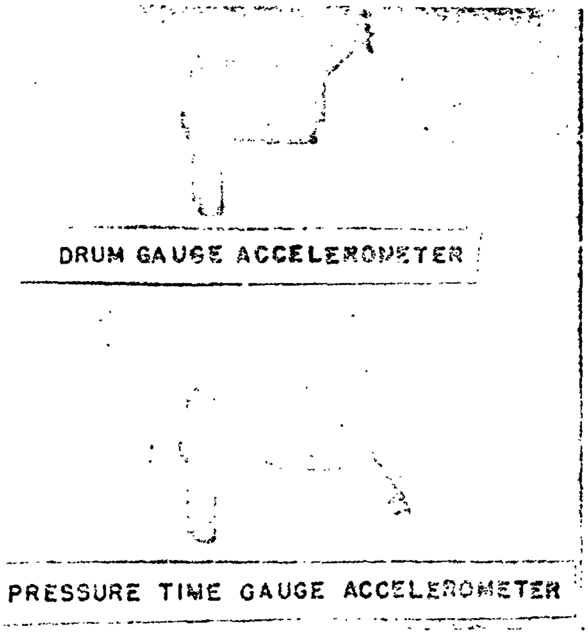

Figure C.12 Accelerometer elements.

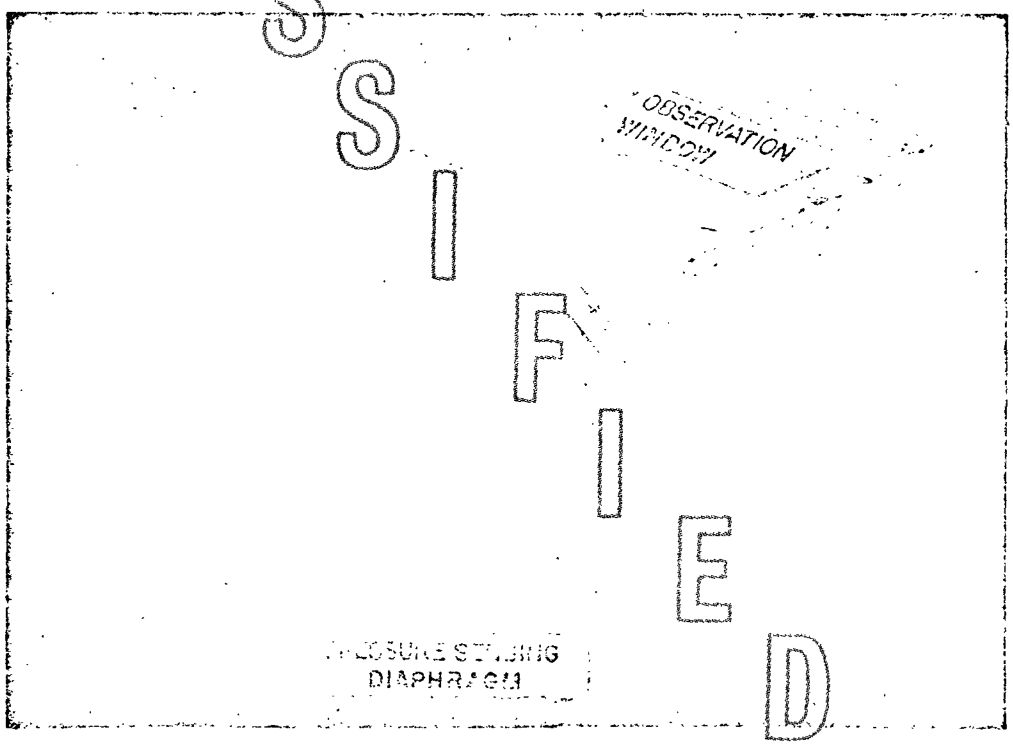

Figure C.13 Very-low-pressure gage.

[redacted]

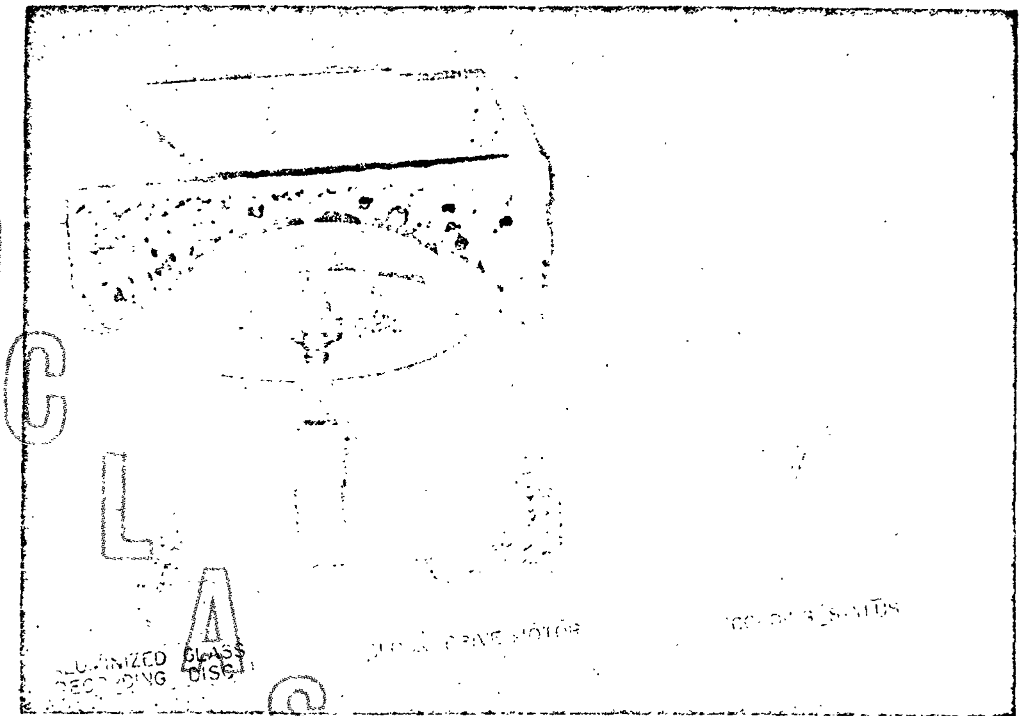

Figure C.14 Very-low-pressure gage, disassembled.

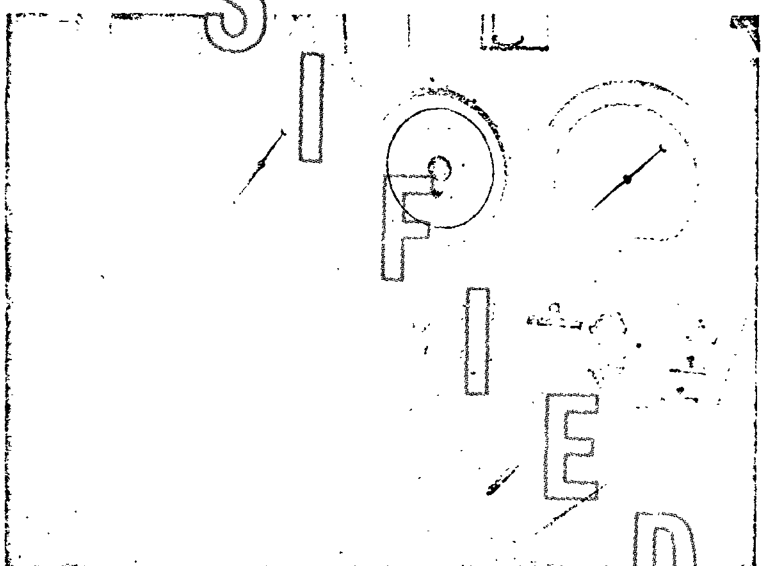

Figure C.15 Operation of calibration panel.

[redacted]

Figure C.16 Pressure-time gage assembled to 3-inch pipe mount.

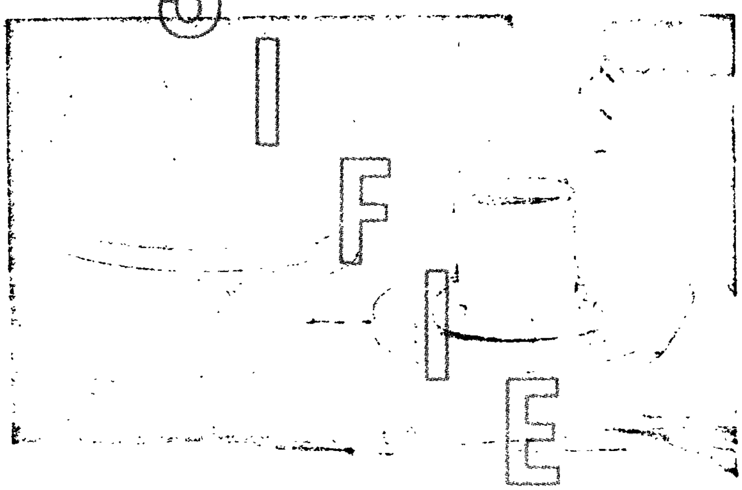

Figure C.17 Peak pressure gage, assembled.

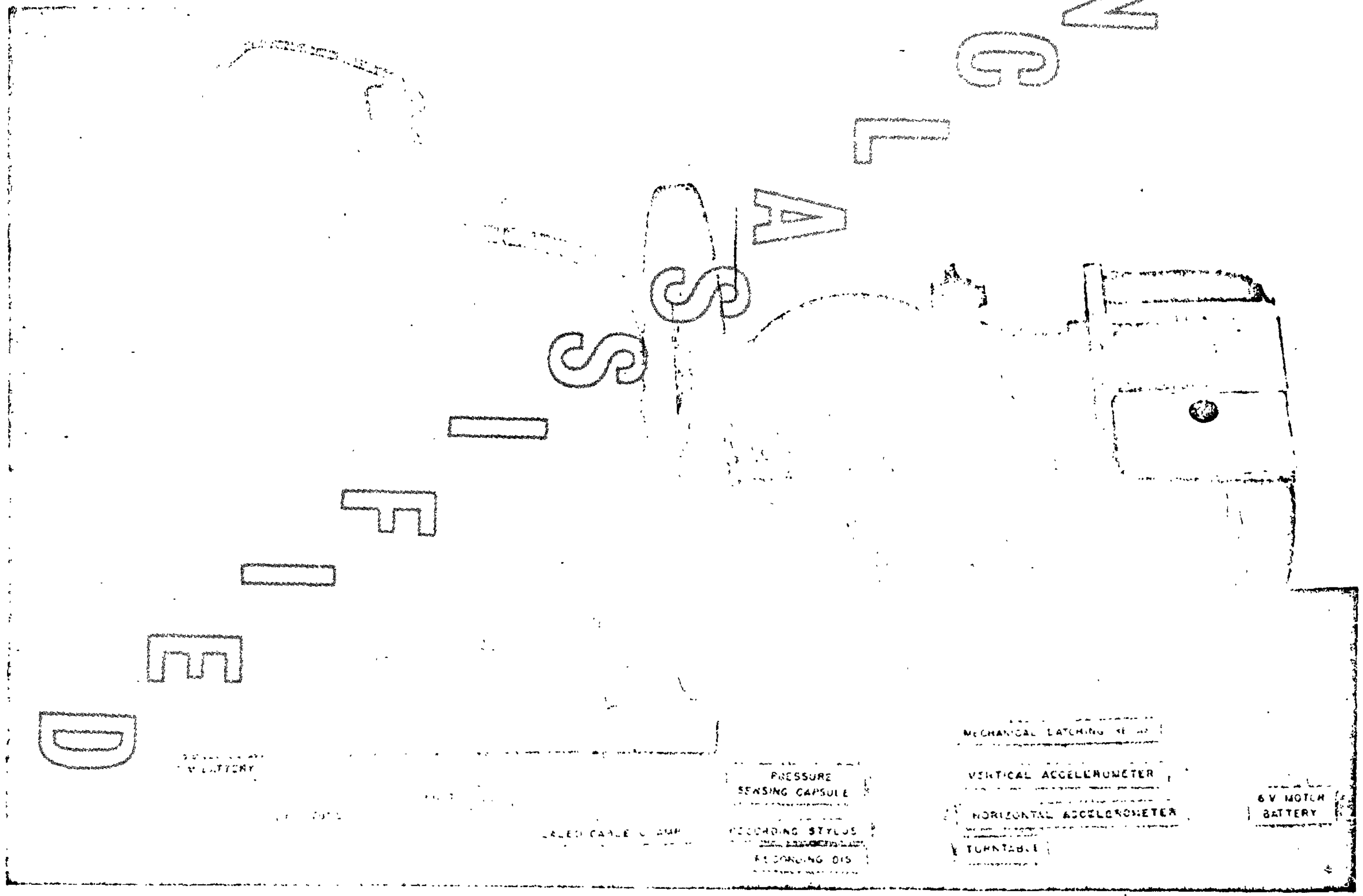

Figure C.18 Pressure-time gage showing accelerometer elements.

[redacted]

Appendix D

POSTSHOT PRESSURE-TIME GAGE INSPECTION

Many of the gages were inspected after the shot to obtain information applicable in explaining defects in their recordings. Thus, by comparison of gage faults and record defects, a correlation could be obtained. Unfortunately, the number of variable factors affecting the gages--pressure ranges, combination of faults, orientation, etc.--was too large to promise a highly reliable correlation, and thus measurements made during the inspection of the gages were concerned more with expressing the faults in relative terms than directly, and were not made to a high degree of accuracy.

External damage to each gage was recorded in terms of the angles through which protruding parts were bent, depth and extent of chipping and sand blasting by flying particles, and burning of exposed flammable materials on the gage.

An internal inspection was made, first, of the turntable drive mechanism to determine the extent of free movement of the turntable shaft along its axis, the amount of wobble of the turntable (the distance its edge could be moved in a direction parallel to its axis of rotation) about any axis perpendicular to the shaft axis, and the slip in the coupling between the motor and turntable (measured as the angle through which the turntable could be turned with a minimum of resistance).

The capsule was checked for any residual distortion or leaks and the stylus arm was checked for parallelism with that radius of the turntable which passed through the center of the capsule, and the stylus was checked to see that it was perpendicular to the recording disc. Any discrepancies were recorded.

The capsule was then removed and the amount of damping and its condition and the quantity of foreign matter in the orifice was recorded. Also, as a triple check on gage assembly lists, capsule numbers were recorded against gage numbers.

The traces of the recording discs were then rechecked for specific defects which could be grouped generally as, (1) the case of no record where either there was no trace whatsoever or where the trace disappeared before it reached its peak, (2) the case of an inaccurate record in which a record was visible but did not agree with other gages in the same cluster, and (3) the case of a distorted record where the trace was instable both as to time and amplitude.

By comparison of the notes on gage inspection and those on the recording discs it was generally easy to find the reason for gage malfunction. Where yields were far above those predicted, failure to achieve a record was caused by such large pressures that the capsules were permanently distorted and often in such a way as to lift the stylus away from the disc. Also, the discs often, under these excess pressures, and occasionally, under lower pressures, cracked and fell off the turntable. At lower pressures, a stopped-up orifice might prevent the formation of a record or, as occurred in one or two cases, the failure of the timing arrangement allowed the gage to continue running until a reference line had been scratched on the disc so broad that it masked a small record. In a few other cases, the reason for lack of record was not isolated.

In some instances records were obtained but differed from those produced by the other gages at the same station or presented unlikely characteristics. Several possible explanations have been offered, some of these being turbulence created at the front gages causing an erroneous pressure to be measured by the rear gages, dynamic effects which cause the responses of the various pressure elements to fluctuate about their static calibration responses by differing amounts, variations in the degree of damping of the capsules, and obstructions which have found their way into the orifice. As yet, a thorough investigation has not been made of the first three cases, but where the top of a record was clipped above a certain pressure, it was found that some of the permatex which was used to seal the element gaskets had been squeezed into the orifice thus forming a sort of pressure sensitive valve that was forced closed after the pressure reached a certain value and which did not reopen until the outside pressure had decayed sufficiently that the air trapped inside the capsule could force the "valve" open again. In another instance of an erroneous record the orifice was found to be jammed with a very fine, hard packed dust.

The most prevalent case and, thus, the most disturbing was that of distorted records. When an attempt is made to compare the gage inspection data with the records an unfortunately scattered array of data presents itself, for each gage has its own peculiar combination of turntable wobble, end play, and shaft slippage and very few of the gages are submitted to the same magnitude of blast pressure or intensity of shocks caused by flying debris (as indicated by depth of chips on gage surfaces). And, again, it may be difficult to separate over-shoot in the record from the effect of vibrations except where an indication of the extent of damping is given. Even a process of listing the gages in the order of the severity of a particular fault and then looking for a trend in the corresponding records is complicated by the interplay of separate faults, e.g., the same amount of turntable wobble in two gages in the same pressure range may give varying effects on the record depending on the angle the stylus arm makes with the plane of the turntable.

A cursory examination of the recorder and its comparison with the notes on the gages, neglecting as it would [illegible] the interplay of gage defects, points to the wobble in the [illegible] as the chief cause of the amplitude distortion of the records. It is difficult to tell whether the backlash present in the gears of all the drive motors is alone responsible for the distortion of the records on the time axis or whether it is a combination of this and the slip in the coupling together. This is a valid point of doubt since the turntable shafts in some of the gages bound in their bearings thus creating a braking effect (similar to that of the braking added to some of the modified P_t gages) which would tend to prevent backlash.

[redacted]

A detailed examination of the data was made at BRL and the following modifications were made on the gages used on Operation TEAPOT.

(1) Revision of the turntable drive bearing system.

(2) An improved coupling between turntable and motor to eliminate the motor reduction gear backlash and slip at the couplings.

(3) An improved method of mounting the recording disc to prevent its cracking under shock.

(4) Research on the control of quantity and kind of damping material best suited.

(5) Revising the specifications on the placement of the stylus arm on the capsule to insure that it moves parallel to the plane of the turntable.

[redacted]

Appendix E
GROUND SURFACE ACCELERATION MEASUREMENTS

E.1 INTRODUCTION

During the past year the Explosion Kinetics Branch of BRL has undertaken the problem of developing and proving the feasibility of a self-contained, self-recording scratch type accelerometer.

After considering several methods of approach it was decided to modify the Engineering Research Associates (ERA) elements already on hand. Actually the only components of the ERA elements that were retained were the springs. Essentially the prototype BRL accelerometers were constructed somewhat like the original ERA elements, save the modifications needed to convert the elements to a self-recording type.

E.2 INSTRUMENTATION

E.2.1 Elements

The new accelerometer elements have a mounting post, an ERA spring, a mass at the end of the spring, a stylus spring with stylus attached to the end of the mass and a damping plate. Figure C.12 shows the complete assembly for both the standard gage and the drum gage elements. The most critical members of the elements are the ERA springs and the weights of the masses. A frictional damping between the stylus and recording disc was used rather than a viscous fluid damping.

E.2.2 Mounting of Elements

The elements that were mounted in the P_t gages were oriented in a vertical and horizontal plane so that vertical and horizontal acceleration could both be recorded on the same disc as the pressure versus time record. This mounting system is shown in Figure C.18. The drum gage had only one element which measured vertical accelerations. The gage and mounting post are shown in Figure C.6.

E.3 CALIBRATION OF ACCELEROMETER ELEMENTS

E.3.1 Static Calibration

The prototype accelerometer elements were calibrated at the Naval Ordnance Laboratories (NOL) facility at White Oak, Maryland. A low speed centrifuge was used to make static calibrations. The centrifuge is known as the "NOL Centrifuge (low speed) XL-1A". A mounting device with a motor driven disc table was used for all calibrations. By setting the mount at varying distances from the axis and varying the speed of the centrifuge motor each element was exposed to its expected range of accelerations. The axis of each element was oriented on a tangent to a radius from the center of the recording disc to obtain optimum results. Each element has a calibration disc so marked and kept as a permanent record of the calibration. A laboratory microscope was used to read the deflection in mils, of the corresponding

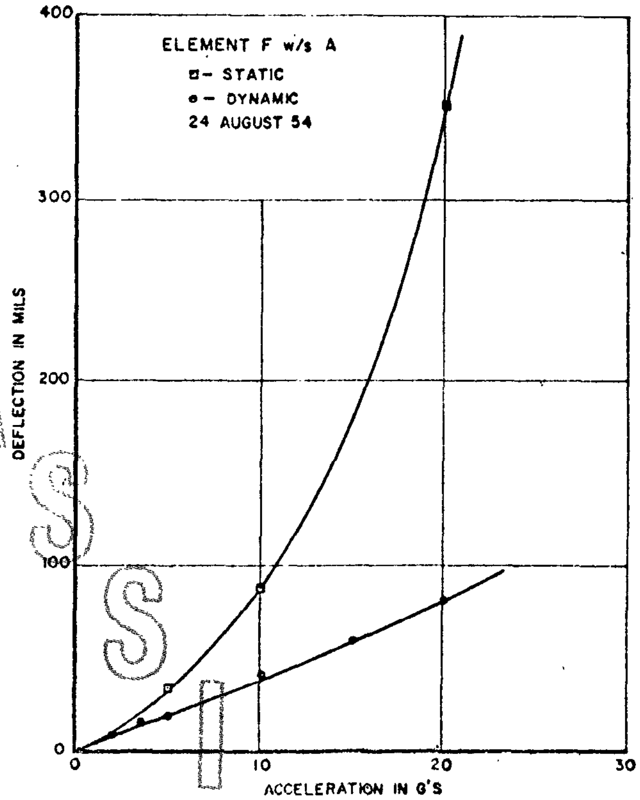

Figure E.1 Typical static and dynamic calibration curve of an air accelerometer element.

accelerations applied to each element. From the compiled results a calibration curve of deflection in mils versus acceleration in G's was drawn for each element.

E.3.2 Dynamic Calibrations

The elements were also given a dynamic calibration on a drop tester. This tester is known as the "NOL Drop Tester (12") Type 1A". The mount used on the centrifuge was also used for the drop test. By varying the drop heights and the lead slugs on the anvil, each element was exposed to selected values of accelerations. The axis of each element was oriented tangent to the radius of the disc to gain optimum results. Typical calibration curves of both static and dynamic accelerations are plotted in Figure E.1.

[redacted]

E.4 RESULTS

Shot 1
Station 122.05
No readable records. Gage only ran a short time. Curves very distorted.

Station 123.03

	Horizontal Acceleration	Vertical Acceleration
Element and range	D (0-20 g's)	F (0-15 g's)
Deflection in mils	190 mils	30 mils
Acceleration in g's	Approx. 50 g's (extrapolated)	7.2 g's
Duration	6.8 seconds	2.2 seconds
Frequency	6 cps	Not readable
Pressure	19 psi	

Station 123.03 was located 15,925 feet from GZ on a reef between Charlie and Dog. Low tide was at 0736 on shot day, leaving most of the gage mounts above the water level. To explain the extremely high horizontal or radial acceleration at this station we must consider that the gage and gage mount acted as a pendulum when the shock wave passed over it. This reading was of no value to ground acceleration, but it is probably an explanation for the failure of some of the pressure-time gages and the distortions of their records. The vertical acceleration is probably a truer value in magnitude of actual acceleration. The shock wave was impressed in a coincidental plane with the gage and gage mount, with the coral reef acting as a baffle to the gage itself.

Shot 2
Station 122.05
No readable records. Gage only ran a short time. Curves very distorted.

Station 122.07
Gage lost. Only two gages recovered from this station.

Station 123.03

	Horizontal Acceleration	Vertical Acceleration
Element and range	H' (0-5 g's)	C (0-15 g's)
Deflection in mils		
1st peak neg	113.4 mils	5.3 mils
2nd peak pos	424.6 mils	10.7 mils
Acceleration in g's		
1st peak neg	6.5 g's	1.5 g's
2nd peak pos	24.2 g's	3.0 g's
Duration	3.8 seconds	.42 seconds
Frequency	9 cps	37 cps
Pressure	15.7 psi	

[redacted]

Station 123.03 was located 16,140 feet from GZ on a reef between Charlie and Dog. There was a low high tide at shot time, again leaving most of the gage mount above the water level.

The high horizontal or radial acceleration was probably produced through the pendulum action of the gage and gage mount. The accelerometer element vibrated at a frequency probably due to the shock wave. This vibration is very clearly impressed on the frequency pattern of the gage mount, which is predominant. Again the vertical acceleration is probably a truer indication of the applied acceleration. The coral reef once more acted as a baffle to the gage. The shock wave was again impressed in a coincidental plane with the vertical axis of the gage.

Shot 3

Station 122.17

Gage did not run until shock wave arrived. If there are any acceleration records they are indistinguishable from the resulting hash during the process of putting the elements in place.

Station 122.19

No vertical acceleration record.

	Horizontal Acceleration
Element and range	I (0-30 g's)
Deflection in mils	
1st peak	1.5 mils
2nd peak	2 mils
3rd peak	2 mils
Acceleration in g's	
1st peak	1.5 g's
2nd peak	2 g's
3rd peak	2 g's
Duration	3.33 seconds
Frequency	Not readable
Pressure	10.5 psi

Station 122.19 was located 5,420 feet from GZ in the clearing on Uncle.

The acceleration indicated on this gage is acceptable within the limits expected.

Station 122.20

	Horizontal Acceleration	Vertical Acceleration
Element and range	L (0-20 g's)	J (0-15 g's)
Deflection in mils	3 mils	4 mils
Acceleration in g's	1 g	1.4 g's
Duration	1.66 seconds	3.89 seconds
Frequency	1.75 cps	Not readable
Pressure	7.4 psi	

Station 122.20 was located 6,520 feet from GZ in the clearing on Uncle.

Both the horizontal and the vertical acceleration records at this station are acceptable within the expected limits.

Station 122.21
No record. Element was not set properly.

Station 124.07
Gage only ran short time.

	Horizontal Acceleration	Vertical Acceleration
Element and range	H (0-5 g's)	A' (0-5 g's)
Deflection in mils		
1st pk neg	96.5 mils	101.4 mils
2nd pk pos	32.2 mils	97.3 mils
Acceleration in g's		
1st pk neg	*	*
2nd pk pos	4.55 g's	*
Duration	Not readable	Not readable
Frequency	Not readable	Not readable
Pressure	2.2 psi	

* Calibration curves are not complete enough to cover these ranges.

Station 124.07 was located 10,900 feet from GZ on Peter.

The readings at this station are probably in great error because the gage did not run.

Station 124.11 R
No visible record.

Station 124.11L
The vertical acceleration record is not clearly defined.

	Horizontal Acceleration
Element and range	A (0-30 g's)
Deflection in mils	
1st peak	2 mils
2nd peak	2.5 mils
3rd peak	2 mils
Acceleration in g's	
1st peak	6 g's
2nd peak	9 g's
3rd peak	6 g's
Duration	Not readable
Frequency	Not readable
Pressure	8.15 psi

[redacted]

Station 124.11 was located 5,596 feet from GZ on Sugar.

NOTE: Readings on Stations 120.08-R, 170.03-R, and P 1 are on drum gages. All records are distorted.

Shot 6

Station 124.16
Record discounted. Excessive oscillations make record questionable.

	Horizontal Accelerations	Vertical Accelerations
Station 124.19		
Element and range	I (0-30 g's)	K (5-40 g's)
Deflection in mils	28.4 mils	11.8 mils
Acceleration in g's	11.5 g's	9.5 g's
Station 124.20		
Element and range	F' (0-40 g's)	E (10-40 g's)
Deflection in mils	16.5 mils	Not readable
Acceleration in g's	15.0 g's	- -
Station 124.22		
Element and range	D (0-20 g's)	C (0-20 g's)
Deflection in mils	84.2 mils	55.8 mils
Acceleration in g's	10.4 g's	9.8 g's
Station 124.23		
Element and range	J (0-15 g's)	L (0-20 g's)
Deflection in mils	23.3 mils	No record
Acceleration in g's	5.4 g's	- -
Station 124.24		
Element and range	F (0-20 g's)	K' (0-20 g's)
Deflection	23.3 mils	36.0 mils
Acceleration in g's	3.5 g's	4.2 g's
Station 124.27		
Element and range	H (0-5 g's)	A' (0-5 g's)
Deflection in mils	13.8 mils	8.5 mils
Acceleration in g's	1.8 g's	1.0 g's

E.5 CONCLUSION

It is the author's opinion that these scratch-type accelerometers are feasible and recommend that more time and manpower be used to develop them for their maximum efficiency.

[redacted]

Appendix F
THE VERY LOW PRESSURE (VLP) GAGE

F.1 INTRODUCTION

The very low pressure (VLP) gages used in Operation CASTLE were designed and constructed at BRL. They are simple in operation and require a minimum of maintenance. The stations for this operation were attended by one technician although they can be modified to start at zero time by the use of a photo-cell initiation circuit. The gage is self-contained and self-recording and is capable of measuring pressure differentials in the 0 to 0.500 psi range with a sensitivity of 0.001 psi.

F.2 DESCRIPTION

The VLP gage itself consists of four major parts:

1. A pressure sensing diaphragm which consists of a single phosphor-bronze convoluted diaphragm, 5-3/4 inches in diameter, having a stylus arm with a sapphire tipped needle soldered to the center to transmit its motion to the recording disc.

2. The recording disc is a five-inch diameter glass disc, 1/16 inch thick, with an aluminized coating. A trace of less than one mil wide and approximately 4-3/4 inches in diameter is recorded. The width of the trace will vary with the quality of the coating and stylii point.

3. The drive motor was a spring driven chart drive type with a recording speed of one revolution per four hours. The turntable which held the recording disc was mounted directly to the drive shaft of the motor.

4. The gage case is a steel box eight inches square on the front and seven inches deep with a removable cover on the top. A rubber gasket was used to seal the lucite cover making the gage air tight. Two views of the gage are shown in Figures C.13 and C.14.

F.3 CALIBRATION

The gages were not completed soon enough to allow an accurate calibration before being shipped to the field. They were however calibrated soon after their return to the laboratory. Using a small valve on the side of the gage, a vacuum system was used to calibrate this type VLP gage.

[redacted]

F.4 FIELD OPERATION

In field use, the gage is placed in a louvered box which serves to minimize wind effects. The spring drive motor is wound and started approximately six hours before the desired recording time. During this period, the pressure relief screw is open permitting pressure equalization. This permits the base line scratched on the disc to be a true representation of the ambient pressure. Just prior to the expected phenomena, the pressure relief screw is closed making the gage completely pressure tight.

At some time prior to or following the recording of the pressure phenomena, time pips are placed on the record disc. This is accomplished by removing the relief screw and inserting a small rubber tube. A very slight suction is applied by mouth deflecting the diaphragm and producing a sharp pip on the record disc. A number of pips are recorded in this manner at accurately known time intervals.

F.5 PRESENTATION OF DATA

The data recorded by the VLP gages are presented in two forms. One form is the actual enlarged photograph and the other form is a linearized curve of pressure versus time. These are presented to show the correlation between this method of measurements and those made by Sandia Corporation using microbarographs (see Figures F.1, F.2, F.3, F.4). Four representative records were chosen for this comparison.

F.6 DISCUSSION AND RECOMMENDATIONS

The comparison of the records made by BRL and SC at the same locations show excellent correlation. The only difference being on Site Elmer on Shot 1 where the record from the BRL gage shows evidence of a leak as it does not record all of the pressure flux indicated by the SC record.

In addition to being simple to operate, and constructed of few parts the gage records directly on the recording disc and does not require the additional calibration of amplifiers and recording equipment. The amplification of the record is obtained through the optic system of a toolmaker's microscope.

The gages were usually placed in the field six to eight hours before shot time and could be left unattended, if necessary. For an inexpensive, self-recording, sensitive pressure time gage the VLP gage has proven itself to be reliable and accurate.

[redacted]

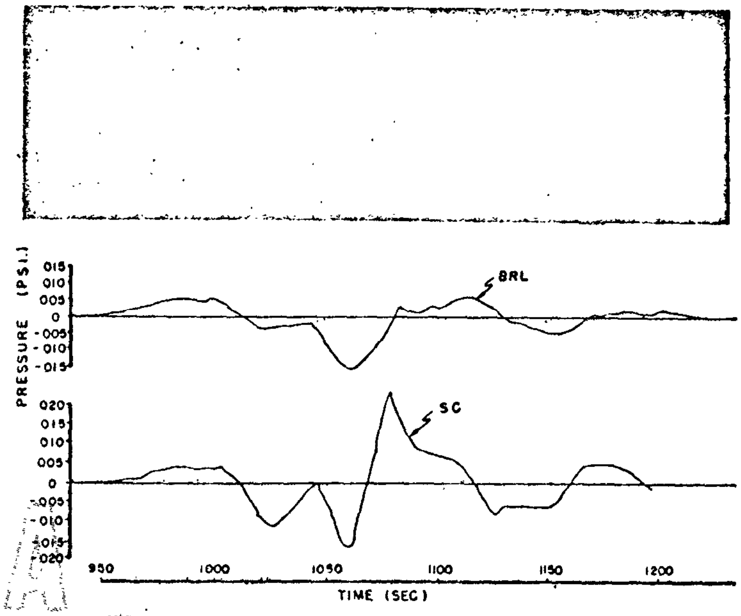

Figure F.1 Comparison of VLP, and microbarograph gage records from Site Elmer on Shot 1.

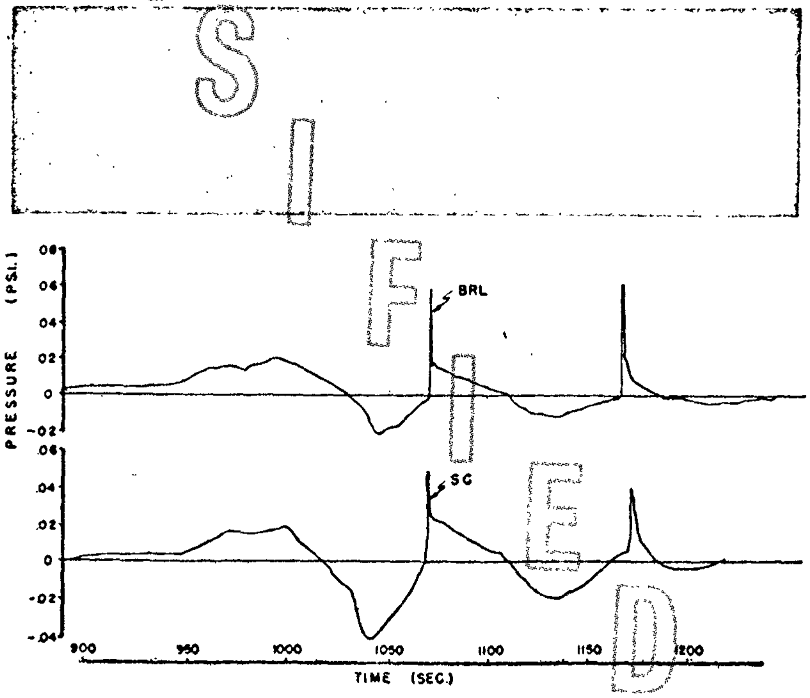

Figure F.2 Comparison of VLP, and microbarograph gage records from Site Elmer on Shot 2.

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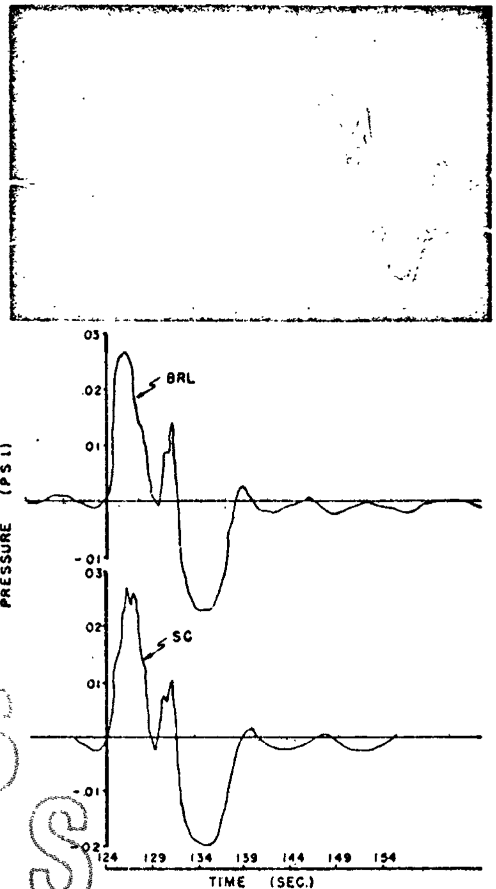

Figure F.3 Comparison of VLP, and microbarograph records from USS Curtis on Shot 3.

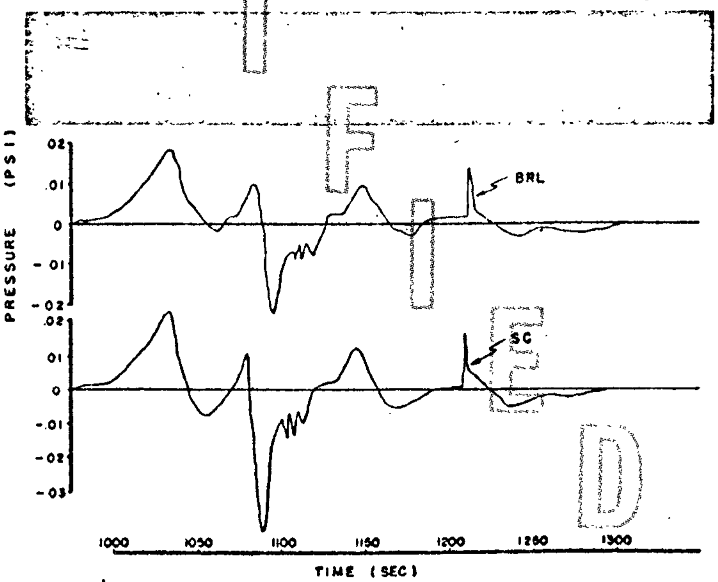

Figure F.4 Comparison of VLP, and microbarograph records from Site Elmer on Shot 4.

[redacted]

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27 Secretary, The Antiaircraft Artillery and Guided Missile School, Ft. Bliss, Texas. ATTN: Maj. Gregg D. Breitegan Dept. of Tactics and Combined Arms
28 Commanding General, Army Medical Service School, Brooke Army Medical Center, Ft. Sam Houston, Tex.
29 Director, Special Weapons Development Office, Headquarters, CONARC, Ft. Bliss, Tex. ATTN: Capt. T. E. Skinner
30 Commandant, Walter Reed Army Institute of Research, Walter Reed Army Medical Center, Washington 25, D.C.
31 Superintendent, U.S. Military Academy, West Point, N.Y. ATTN: Prof. of Ordnance
32 Commandant, Chemical Corps School, Chemical Corps Training Command, Ft. McClellan, Ala.
33 Commanding General, Research and Engineering Command, Army Chemical Center, Md. ATTN: Deputy for RW and Non-Toxic Material
34- 35 Commanding General, Aberdeen Proving Grounds, Md. ATTN: for Director, Ballistics Research Laboratory
36 Commanding General, The Engineer Center, Ft. Belvoir, Va. ATTN: Asst. Commandant, Engineer School
37 Commanding Officer, Engineer Research and Development Laboratory, Ft. Belvoir, Va. ATTN: Chief, Technical Intelligence Branch
38 Commanding Officer, Picatinny Arsenal, Dover, N.J. ATTN: ORDBB-TK
39 Commanding Officer, Army Medical Research Laboratory, Ft. Knox, Ky.
40- 41 Commanding Officer, Chemical Corps Chemical and Radiological Laboratory, Army Chemical Center, Md. ATTN: Tech. Library
42 Commanding Officer, Transportation R&D Station, Ft. Eustis, Va.
43 Director, Technical Documents Center, Evans Signal Laboratory, Belmar, N.J.
44 Director, Waterways Experiment Station, PO Box 631, Vicksburg, Miss. ATTN: Library
45 Director, Armed Forces Institute of Pathology, Walter Reed Army Medical Center, 6825 16th Street, N.W., Washington 25, D.C.
46 Director, Operations Research Office, Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase, Md. Washington 15, D.C.
47- 48 Commanding General, Quartermaster Research and Development Command, Quartermaster Research and Development Center, Natick, Mass. ATTN: CBR Liaison Officer

NAVY ACTIVITIES

49- 50 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-36
51 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-03EG
52 Director of Naval Intelligence, D/N, Washington 25, D.C. ATTN: OP-922V
53 Chief, Bureau of Medicine and Surgery, D/N, Washington 25, D.C. ATTN: Special Weapons Defense Div.
54 Chief, Bureau of Ordnance, D/N, Washington 25, D.C.
55 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 348
56 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
57 Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D.C.
58- 59 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
60 Chief of Naval Research, Department of the Navy Washington 25, D.C. ATTN: Code 811
61 Commander-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, Calif.
62 Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Va.
63- 66 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code A03H
67 President, U.S. Naval War College, Newport, R.I.
68 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
69 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
70 Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School
71- 72 Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School)
73 Commanding Officer, Air Development Squadron 5, VX-5, U.S. Naval Air Station, Moffett Field, Calif.
74 Commanding Officer, U.S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course
75 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. [illegible]
76 Commander, [illegible] Laboratory, Silver Spring 19, Md. [illegible]
77 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R
78 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
79 Officer-in-Charge, U.S. Naval Civil Engineering Res. and Evaluation Lab., U.S. Naval Construction Battalion Center, Port Hueneme, Calif. ATTN: Code 753

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80 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda 14, Md.

81 Director, Naval Air Experimental Station, Air Material Center, U.S. Naval Base, Philadelphia, Penn.

82 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Mrs. Katherine H. Cass

83 Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif.

84- 85 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco 24, Calif. ATTN: Technical Information Division

86- 90 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C. ATTN: AER-AD-41/20

91- 92 Commanding Officer and Director, David W. Taylor Model Basin, Washington 7, D.C. ATTN: Library

93 Commander, U.S. Naval Air Development Center, Johnsville, Pa.

94 CINCPAC, Fleet Post Office, San Francisco, Calif.

95 Commander, Norfolk Naval Shipyard, Portsmouth, Va. ATTN: Code 270

AIR FORCE ACTIVITIES

96 Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O

97 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis

98 Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.

99 Director of Research and Development, DCS/D, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.

100-101 Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-IB2

102 The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pre. Med. Div.

103 Asst. Chief of Staff, Intelligence, Headquarters, U.S. Air Forces Europe, APO 633, New York, N.Y. ATTN: Directorate of Air Targets

104 Commander, 497th Reconnaissance Technical Squadron (Augmented), APO 633, New York, N.Y.

105 Commander, Far East Air Forces, APO 925, San Francisco, Calif. ATTN: Special Asst. for Damage Control

106 Commander-in-Chief, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: Special Weapons Branch, Inspector Div., Inspector General

107 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch

108 Commander, Air Defense Command, Ent AFB, Colo.

109-110 Research Directorate, Headquarters, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico. ATTN: Blast Effects Research

111 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDCN

112 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: Adj./Tech. Report Branch

113-114 Director, Air University Library, Maxwell AFB, Ala.

115-122 Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training

123 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O

124-125 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.

126-131 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOSI

132-133 Commander, Air Force Cambridge Research Center, LG Hanscom Field, Bedford, Mass. ATTN: CRQST-2

134-136 Commander. Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library

137-138 Commander, Lowry AFB, Denver, Colo. ATTN: Department of Special Weapons Training

139 Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.

140-141 The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division

142 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Analysis Office

143 Commander, Eighth Air Force, Westover AFB, Mass. ATTN: Operations Analysis Office

144 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Analysis Office

145 Commander, Western Development Div. (ARDC), PO Box 262, Inglewood, Calif. ATTN: WDSIT, Mr. R. G. Weitz

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

146 Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D.C. ATTN: Tech. Library

147 U.S. Documents Officer, Office of the U.S. National Military Representative, SHAPE, APO 55, New York, N.Y.

148 Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D.C.

149 Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.

150 Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary

151 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.

152 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group

153-157 Commander, FC, AFSWP, PO Box 5100, Albuquerque, N. Mex. ATTN: Deputy Chief of Staff, Weapon Effects Tests

158-168 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Documents Library Branch

ATOMIC ENERGY COMMISSION ACTIVITIES

169-171 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For DMA)

172-173 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman

174-176 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero

177-179 University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Clovis G. Craig

180 Weapon Data Section, Technical Information Service Extension, Oak Ridge, Tenn.

181-210 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

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