POR-2200(EX)
(WT-2200)(EX)
EXTRACTED VERSION

AD-A995 368

OPERATION SUN BEAM, SHOT SMALL BOY

Project Officer's Report—Project 1.1

Nuclear Airblast Phenomena

J. H. Keefer, Project Officer
R. E. Reisler
E. G. Schwartz
Explosion Kinetics Branch
Terminal Ballistics Laboratory
Ballistic Research Laboratories
Aberdeen Proving Ground, MD

18 December 1963

NOTICE:

This is an extract of POR-2200 (WT-2200), Operation SUN BEAM, Shot Small Boy, Project 1.1.

Extracted version prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

1 September 1985

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A995 368

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY: N/A since Unclassified

2b DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A since Unclassified

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S):

5 MONITORING ORGANIZATION REPORT NUMBER(S): POR-2200(EX) (WT-2200)(EX)

6a NAME OF PERFORMING ORGANIZATION: Explosion Kinetics Branch Ballistic Research Labs.

6b OFFICE SYMBOL (If applicable):

7a NAME OF MONITORING ORGANIZATION: Defense Atomic Support Agency

6c ADDRESS (City, State, and ZIP Code): Aberdeen Proving Ground, MD

7b ADDRESS (City, State, and ZIP Code): Washington, DC

8a NAME OF FUNDING / SPONSORING ORGANIZATION:

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code):

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): OPERATION SUN BEAM, SHOT SMALL BOY; Project Officer's Report—Project 1.1 Nuclear Airblast Phenomena, Extracted Version

12 PERSONAL AUTHOR(S): Keefer, J.H.; Reisler, R.E.; and Schwartz, E.G.

13a TYPE OF REPORT:

13b TIME COVERED FROM ______ TO ______

14 DATE OF REPORT (Year, Month, Day): 631218

15 PAGE COUNT: 142

16 SUPPLEMENTARY NOTATION: This report has had sensitive military information removed in order to provide an unclassified version for unlimited distribution. The work was performed by the Defense Nuclear Agency in support of the DoD Nuclear Test Personnel Review Program.

17 COSATI CODES

FIELD	GROUP	SUB-GROUP
18	3	
19	4	

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number):
Sun Beam
Small Boy
Airblast

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The objectives of this project were to: (1) measure airblast phenomena in the high-, moderate- and low-pressure regions along a blast line; (2) integrate new data with existing nuclear blast information; and (3) evaluate new types of pressure transducers and recorders for use on nuclear tests.

Information which was obtained is contained in the form of tables and graphs. A tabulation indicating success of the instrumentation and a discussion of anomalies is presented.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL: Mark D. Flohr

22b TELEPHONE (Include Area Code): (202) 325-7559

22c OFFICE SYMBOL: DNA/ISCM

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

OPERATION SUN BEAM

SHOT SMALL BOY

PROJECT OFFICERS REPORT—PROJECT 1.1

NUCLEAR AIRBLAST PHENOMENA (U)

J.H. Keefer, Project Officer

R.E. Reisler
E.G. Schwartz

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

FOREWORD

Project 1.1 was instituted as a research project by DASA to study the airblast produced by the Small Boy detonation and correlate this information with existing data. Particular emphasis was placed on the high-pressure region with attention given to the wave shapes produced at all pressure levels. Prototype gages and recording systems were tested to further research efforts in the instrumentation field.

This report is organized to present the data with discussion in the main body. A complete description of the instrumentation, related calibration, and associated techniques is described in Appendixes A through C. Photographs of the records are presented in Appendix D.

ABSTRACT

The primary objective of Project 1.1 was to obtain data on overpressure and dynamic pressure which were produced from Shot Small Boy, of Operation Sun Beam. Free-field measurements in the range from 10,000 psi down to 4 psi were planned.

Information which was obtained on this shot is contained in the form of tables and graphs. A tabulation indicating success of the instrumentation and a discussion of anomalies is presented.

The overpressure-time wave shapes at Stations 501.12, 501.13, and 501.14 indicated that a precursor wave existed between 380 and 680 feet ground range. The measured peak overpressures agreed with the predicted near-ideal overpressure distance curve and did not show the usual depressions that accompany nonclassical blast conditions.

CONTENTS

TABLES

FIGURES

CHAPTER 1
INTRODUCTION

1.1 OBJECTIVES

The objectives were to: (1) measure airblast phenomena in the high-, moderate-, and low-pressure regions along a blast line; (2) integrate new data with existing nuclear blast information; (3) evaluate new types of pressure transducers and recorders for use on nuclear tests.

1.2 BACKGROUND

A thorough understanding of the airblast parameters associated with any nuclear detonation is mandatory for target evaluation and design in both offensive and defensive situations. The first time that measurements in the high pressure region, that is above 100 psi, were emphasized was 1957, Operation Plumbbob. Here, most of the shots were several hundred feet above the surface, and in some cases the overpressure was measured from ground zero to the very-low-pressure region. The following year, Operation Hardtack provided a large amount of information on large-yield surface bursts. Shot Sugar of Operation Buster-

Jangle provided a limited amount of information from a small yield, detonated near the surface at Nevada Test Site.

with no dynamic pressure measurements.

1.3 PREDICTIONS OF BLAST PHENOMENA

The Small Boy shot was detonated at 10 feet above the surface of Frenchman Flat. Atmospheric pressure and temperature were estimated on the basis of average values for previous shots in Frenchman Flat. Figure 1.1 contains the estimated peak overpressure versus distance curve for Shot Small Boy using the near-ideal height-of-burst curves from Reference 1. Nonideal precursor waves have been recorded on many shots fired in Frenchman Flat. The data from these past shots, along with data from all precursor-forming shots, have been used to establish precursor-forming criteria as shown in Figure 1.2. These criteria showed that classical blast waves should have been recorded on Shot Small Boy.

Even though this was a nonprecursor shot, it was not surprising to see some precursor effects in the high-pressure region since very little data exist from past nuclear shots. The prediction of dynamic pressure from Reference 1 is shown in Figure 1.3 .

A comparison of the shot parameters for Small Boy and Shot Sugar of Buster Jangle shows them to be very similar. Shot Sugar was a near-surface shot fired in the Yucca Flat Area.

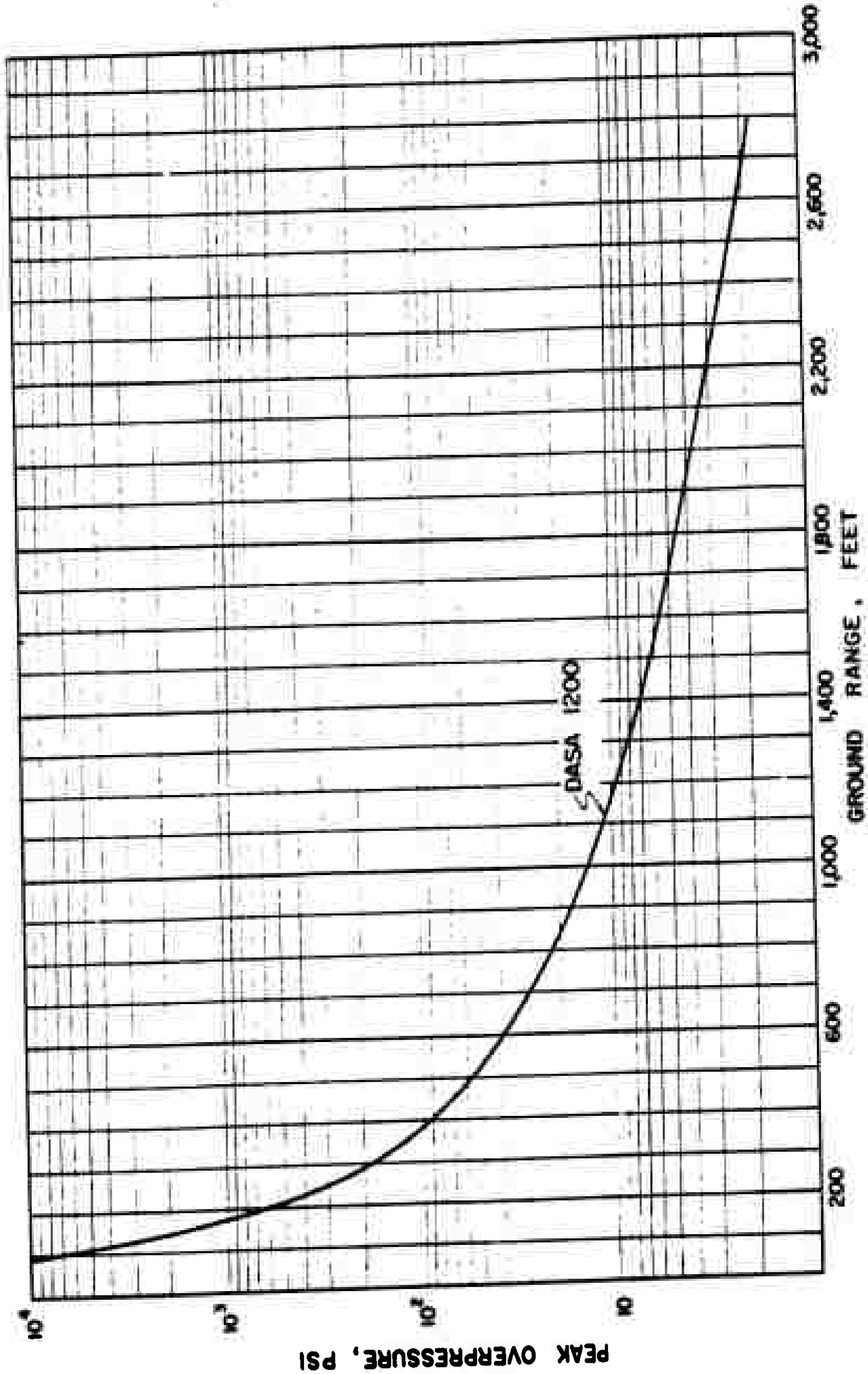


Figure 1.1 Predicted peak overpressure versus distance.

Page 17 deleted.

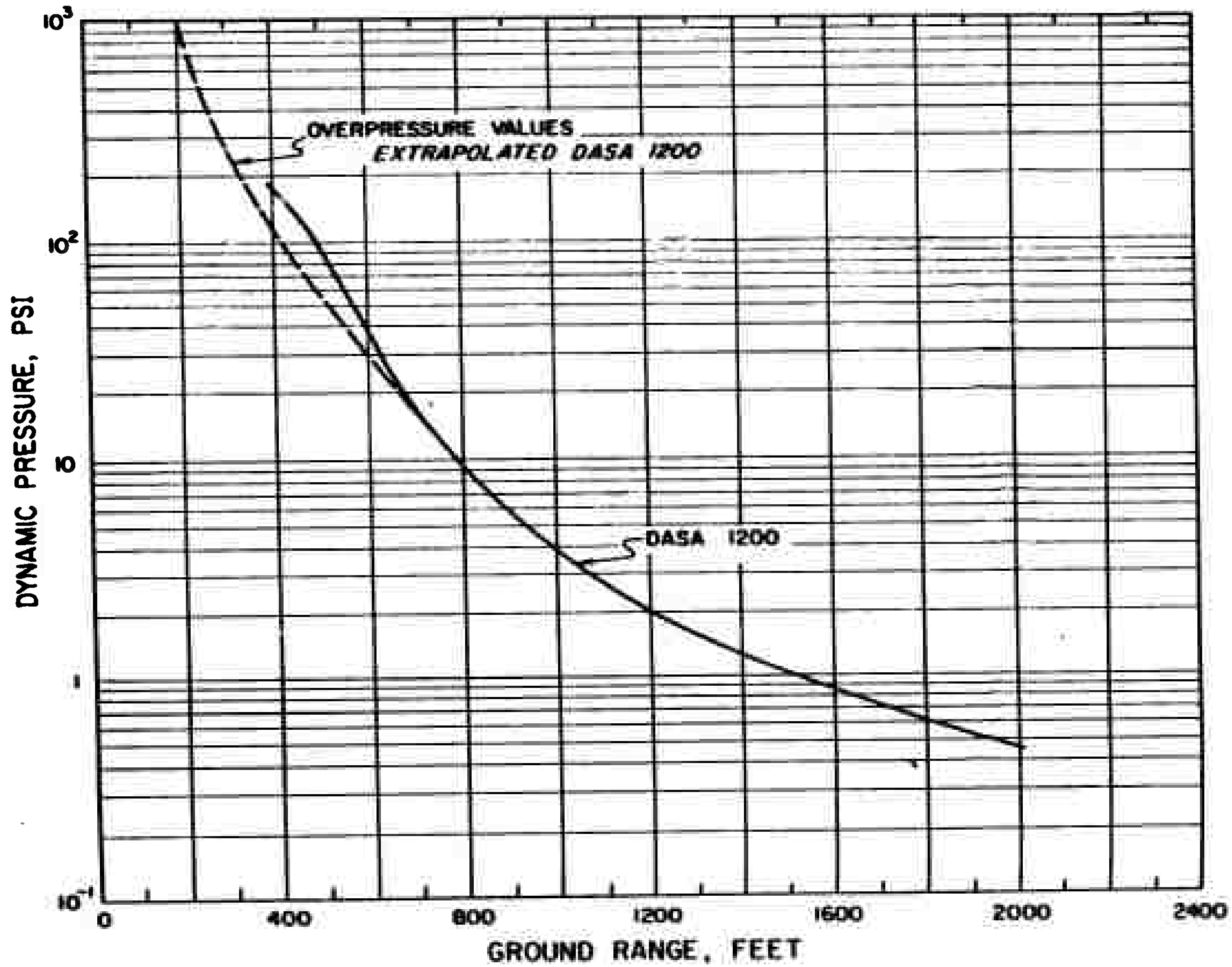


Figure 1.3 Predicted peak dynamic pressure versus distance.

CHAPTER 2

OPERATIONS

2.1 GENERAL

An extensive number of ground baffle overpressure gages, both electronic and self-recording types, were used along the main blast line in order to compare newly designed pressure transducers with standard types used on past nuclear tests. Nine dynamic pressure measurements also were attempted at seven different stations along the blast line. The blast line layout is shown in Figures 2.1 and 2.1a. Schematics of the gage mounts are shown in Figures 2.2 and 2.3.

The location of various type pressure gages, as shown in Table 2.1, was such that the first objective of this project would be achieved even though the new gages, which were untested in a nuclear environment, failed. The new transducers were placed along the blast line in order to obtain a comparison with the standard ones and, at the same time, expose them to a wide range of parameters. Some of the new transducers used on this shot have been successfully used to measure blast parameters from many large high-explosive (HE) charges. A large number of these were used to measure blast by the U. S. Test Group that participated in the Canadian 100-ton TNT shot in 1961.

2.2 INSTRUMENT SHELTER REQUIREMENTS

Electronic recording instruments and auxiliary equipment were housed in an underground quonset-type building with concrete reinforced ends. The shelter was partitioned to form a recording instrument portion approximately 40 feet long and a power room, containing the batteries and dc converters, approximately 15 feet long. The building width was 25 feet (Figure 2.4). During the preparation phase, a ramp was utilized to enter the shelter through an air-lock door. The instrumentation section of the shelter was pressurized with selectable fresh or cooled filtered air. The air was exhausted out through the power room ceiling entry or through the air-lock doorway, when open. The power room exhaust carried away the excessive heat and gasses created by the power and battery equipment, while the pressurization minimized extensive dust intrusion into the shelter.

Work benches lining both walls of the shelter facilitated use of the dual row of instrument benches along the center portion. A signal cable shelf, overhead and between the center rows of instrument benches, carried the necessary signal cables to each instrument (Figure 2.5).

The power room contained shelves of batteries and converters, all feeding to panel switching boards for ease of selecting charged batteries for system power or feeding charging current to any set of batteries. Power cables from the panel were fed under the partition through a trough in the floor, to the proper instruments (Figures 2.6 and 2.7).

Power for the shelter was furnished by one generator during the calibration phase. During the event, power was obtained solely from batteries.

The final button-up phase of the shelter operation consisted of sandbagging the air-lock entry door, removing the generators, and covering the top hatchway with a protective layer of sandbags.

2.3 ELECTRONIC INSTRUMENTATION

2.3.1 Recording System Utilization. The recording shelter contained the major portion of Project 1.1 instrumentation in addition to the instrumentation for Project 3.3. All blast line transducers of the variable reluctance type were recorded on Consolidated Electro-Dynamics (CEC), (Figure 2.8) System D, 3-kc carrier systems. Transducer signals of the strain-bridge type were recorded on a CEC magnetic tape, frequency modulated (FM) system.

Project 1.1 recording systems, located in the shelter, were all of standard varieties adapted for use in field tests. The 3-kc systems are capable of 0 to 500 cps response, while the FM magnetic tape system response was from 0 to 10 kc. Electronic instrumentation and system details are discussed more fully in Appendix A. In general, the systems of higher response were utilized for channels of higher pressure-response recording, especially at the close-in stations of Project 1.1. In addition to the instrumentation in the instrument shelter, two self-contained, especially built, miniature tape recorders were utilized. These magnetic tape recorders, broadband FM with 0- to 10-kc response, were designed to withstand high shock environment. The recorders were conceived with the intent of eliminating the requirements for long cable and trench lines, expensive instrument shelters, and deleterious effects from electromagnetic pulses on long signal lines. A 14-channel recorder, manufactured by the Leach Corporation and used successfully on several HE tests, was installed at Station 13 of the blast line. Approximately 3 feet of earth and sandbags, supported by a steel plate, protected the recording system. The top of the cylindrical shaped capsule was positioned in a drilled hole beneath the plate, with 1 foot of air space over it. The surface was smoothed to conform to the surrounding terrain.

The other recorder, a 7-channel system, manufactured by the Weber Aircraft Corporation, was buried beneath 4 feet of sandbags at Station 12 of the blast line (Figures 2.9 and 2.10). The Weber recorder was utilized to determine its suitability for future field test commitments. The overcover of sandbags was the only protection given the recorder, in order to subject it to intense field environments. The seven channels were utilized as follows:

Channel 1 - Recorded the output of a voltage controlled oscillator (VCO), external from the recorder package and protected by 1-1/2 inches of lead, while the input was shorted. This test was to determine the shielding effects on the electronics in comparison with a similar internal VCO without the lead shielding.

Channel 2 - Recorded signals from a low-output, bonded-strain type, Detroit Controls pressure transducer to determine overall channel success.

Channel 3 - Recorded the output of a VCO with its input shorted to compare results with the shielded VCO on Channel 1.

Channel 4 - Recorded the 100-kc reference frequency with the time zero pulse superimposed from a solar cell to study circuitry success and radiation effects on the reference oscillator.

Channel 5 - Recorded a 10-kc signal furnished by an oscillator located in the instrument shelter to determine the electromagnetic effects on a long signal line and to determine the reference oscillator stability.

Channel 6 - Recorded the high-output, high-response signals from a solid-state, bridge-type, Micro-Systems pressure transducers to determine channel capabilities without using a dc amplifier.

Channel 7 - Recorded signals from a low-output, Statham, strain-bridge type accelerometer, attached to the recorder transport to determine the acceleration received by the recorder.

Limited effort was made to record piezoelectric transducer signals, using high-speed cameras and scopes. Appendix B contains a detailed description of this instrumentation.

2.3.2 Input Circuitry. System input circuitry is a requirement for nuclear field testing for various reasons. Extreme cable lengths with their associated capacitance, inductance, and resistance effects create a condition whereby the usual laboratory or commercial-type recorders have insufficient range to balance out these effects. Also, the recorders, when used remotely, require added components to record the electrical calibration steps so necessary where long periods of time elapse between calibration and shot.

Previous field testing utilized magnetic recorders and associated input circuitry now considered obsolete. The instrumentation available for this event dictated that new input circuitry be obtained to successfully complete the mission. The Ballistic Research Laboratories (BRL) designed this new circuitry for the CEC carrier systems and contracted its fabrication to Magnetic Instruments Corporation. The circuitry consisted of attenuators, balancing and phasing circuits, calibration resistor terminals, and a remote controlled relay for electrical calibration.

Input circuitry for the CEC magnetic tape system, constructed under contract to Electro-Mechanical Research (EMR), consisted of a bridge power supply for gage excitation, dc amplifiers, and other associated circuits for calibration and balancing. A logic unit, for complete remote control of all phases of the recorder, was an integral part of the circuitry.

Input circuitry for the two miniature recorders was integral with the systems.

2.3.3 Logic Unit and Initiation. Proper control of the recording systems required the use of logic units to sequence the various operations at the proper times during recording in the remote station. Usually, various hard-wire signals from Edgerton, Germeshausen and Grier (EG&G) were available; however, additional signals for postshot functions were required to shut down the equipment. The logic unit, initiated by an EG&G signal, performed these functions.

The logic units for the 3-kc systems were designed by BRL and constructed by the Magnetic Instruments Corporation. The logic unit for the magnetic tape system was constructed as part of its input circuitry as stated above.

The logic unit circuits of the two miniature tape recorders were integral with the systems. Except for adjustment of start-up time and the use of tape sensor stops, the functions performed were essentially the same as described for the systems logic located in the shelter (see Appendix A).

2.3.4 Electromagnetic Pulse Protection, Time Zero (TZ) and Timing. Past experience indicated the electromagnetic pulse of a nuclear shot was of sufficient intensity to damage recording equipment and damage the elements of electronic transducers. A review of techniques used successfully in the past led BRL to install relays for grounding transducer signal lines during the electromagnetic pulse phase of the event. This was done only on the signal lines running into the instrument shelter. The EG&G −2-second signal initiated the relays for signal line grounding, (see Figure 2.11). Blue box relay contacts, in the grounding relay coil power circuit, were opened at TZ, thus restoring the signal lines to normal. The several millisecond delay in the blue box and grounding signal relay box circuit allowed sufficient time for the electromagnetic pulse to diminish before the signal lines were connected. System carrier oscillator outputs were shunted to ground through a 0.1-microfarad capacitor to offer additional pulse protection. Bendix spark gaps, adjusted for 750-volt breakdown, were installed at each transducer, other than the piezo cells, between the signal line shield and ground to drain off excessive voltages built up on the signal cable shield by the electromagnetic pulse.

Time zero was furnished to all tape and paper recorders by driving their galvanometers or tape heads directly from a solar cell exposed to the flash.

Timing was furnished to the paper recorder by driving a galvanometer with a precision set oscillator of 1,000 cps.

2.4 ELECTRONIC TRANSDUCERS

Essentially there were four different types of pressure transducers used on Shot Small Boy. The well-proven Wiancko variable reluctance gages were installed as a back-up for an extensive variety of gages installed along the blast line. Included in the gages, all unproven in nuclear tests, were four new type Wiancko variable reluctance gages, Dynisco and Detroit Control bonded strain gages, and Micro-System bonded solid strain gages. Gage details, characteristics, and specifications are presented in some detail in Appendix A.

2.5 SELF-RECORDING INSTRUMENTATION

Mechanical self-recording pressure time gages of various types were utilized along the blast line of the Small Boy event. Presented in Table 2.2 are the coding, identification, and number of the gages used.

2.5.1 General Gage Description. The BRL mechanical self-recording pressure time gage is a self-contained instrument employing a corrugated diaphragm type sensor. The deflection of the sensor is recorded on a rotating coated disk by an osmium-tipped phonograph needle stylus arm attached to the center of the diaphragm. Overpressure reaches the sensor through an orifice in a protective cover plate mounted in the gage flange. A governed dc motor assures a constant rotation of the turntable at selected speeds of 10 and 20 rpm. Presented in Figure 2.12 is a photograph of a typical gage. A complete description of the gages is presented in Appendix A.

2.5.2 Gage Mounts. A standard mounting system was used for all high-pressure gages. A 3-inch diameter pipe, 4 feet in length, with anchor bars welded to it at various intervals was embedded in concrete at the proper depth for the particular gage. The miniature gages used a pipe reducer fabricated by the contractor to reduce from the 3-inch size on the pipe to the 1-1/2 inch size on the gage. For intermediate pressure ranges, the large gages were mounted on a 3-inch pipe nipple, 8 inches in length, with a 12-inch diameter, 1/4-inch plate welded to the base. The gage and base plate were installed in the ground with the gage flange flush with the ground surface. The miniature gages were mounted on a 1-1/2- by 12-inch pipe threaded at one end and pointed at the other.

The pipe was driven in the ground and the gage installed so that the flange was flush with the ground surface. Gages located in the low-pressure regions were installed in the ground, with the gage flange flush with the surface. Contractor support was utilized for the installation of the gage mounts and holes. The dynamic pressure gages were installed on the standard of mounts utilized by previous projects at NTS. These units were recovered, refurbished, and installed by the contractor. Sand was placed in the pipe supports to reduce the acceleration effects on the gage system. Schematics of the gage mounts are shown in Figures 2.2 and 2.3.

2.5.3 Gage Initation. The majority of the gages used on the Small Boy event were initiated by a hard-wire signal. This signal was supplied by EG&G at -2 seconds and -1 second ; the -1-second signal was used to back up the -2-second signal. A signal distribution box distributed the signal to the individual gages. Miniature relays with a closure time of 5 milliseconds or less were used and mounted in an aluminum container with an O-ring seal around the cover plate. Waterproof connectors were used for the input and output connections.

The cadmium sulfide photoinitiators described in Appendix A were used in selected gages at Stations 14 to 20 and for all gage Stations 21 to 26.

2.6 RECORD READING AND DATA REDUCTION

The deflection time information recorded on the recording media of the various instrumentation systems was read with the aid of automated equipment. Electronic records appearing as oscillograms used a Telereader System in conjunction with a Telecordex and IBM Summary Punch Card System. Self-recording records used a machinist microscope equipped with automatic readout heads to provide inputs to a Telecordex and IBM Summary Punch Card System. The deflection time information appearing on IBM Cards was fed into an automatic computer (EDUAC), together with summary cards containing calibration information. Coding of the computer was made so the output data appeared as pressure, time, and impulse in tabulation forms and on IBM cards. In order to obtain a time plot of the data, the cards served as input to an automatic line plotting machine.

2.7 CALIBRATION

2.7.1 Electronic Gages. Inherent nonlinearities, sensitivity to line length, and other impedance effects required that system calibrations be made after installation in the field. Steady pressure, controlled by a system of regulators, was applied to the pressure transducers through an adapter fitting screwed over the sensing element. The regulators were contained in portable control boxes. Dial gages, having ranges adequate to indicate all required pressures with an accuracy of 0.5 percent, and pretested with a dead weight tester, were used. Steady pressures were applied after installation of the transducers and recording systems, with positive pressures of 20, 40, 60, 80, 100, and 120 percent of the predicted pressure being applied. Extensive pretest laboratory calibrations and evaluations were performed. All pressure transducers were tested in the BRL shock tubes for comparison with dynamic tests against a standard crystal gage. The shock tube facilities enabled all gages to be tested with a square-wave input of various durations up to the 1,000-psi level (see Appendix C). The variable reluctance Wiancko transducers were orifice-adjusted to give the ideal overshoot of approximately 7 percent. Many problems of gage mounting became apparent during these tests. The major problems of clearances and tolerances of delicate gage fits were solved. The bonded strain type gages were found to be temperature sensitive. A film of grease over the sensing element solved this problem. Gage comparisons were found to check quite satisfactorily.

2.7.2 Self-Recording Gages. Calibration of the self-recording gage pressure sensors was performed in the laboratory by project personnel. A commercially available portable calibrator with interchangeable dial gages was used to apply static pressure to the sensors. The dial pressure gages were checked for accuracy prior to use with a dead weight tester. Figure 2.13 illustrates the calibration equipment. A rectangular aluminized glass blank, mounted on a movable carriage within a fixture with the sensor, enabled the deflection of the element to be recorded. Reading of the deflection was accomplished with the aid of a machinist microscope and a pressure versus deflection plot made for each element.

The disk-drive motors were checked for constancy of rpm with an accurate timer in the field laboratory prior to the installation of the sensors. Previous laboratory tests had yielded the start-up time characteristics of the Hayden motors.

TABLE 2.1 CONTINUED

Station	Distance	Type Gage	Range	100% Cal.	Mount	Recorder	Sensor
	ft		psi	psi			
501.08	210	Dynisco	2,500	2,300	Q III	FM	4 Arm Strain Bridge
501.08	210	Dynisco	500	500	Q III	FM	4 Arm Strain Bridge
501.08	210	Detroit Control	500	500	I	FM	4 Arm Strain Bridge
501.08	210	PGS	1,000		V	Self Recording	Bendix Diaphragm
501.08	210*	PHS-1S	300		V	Self Recording	Capsule & USG Diaphragm (Neg.)
501.08	210*	PHS-1S	800		V	Self Recording	Timer, Capsule
501.08	210	PHS-1S	800		V	Self Recording	Diaphragm USG
501.09	250	Microsystems	500	300	I	Leach	4 Arm Strain Semiconductor
501.09	250	Microsystems	1,000	1,180	Q III	Leach	4 Arm Strain Semiconductor
501.09	250	PHS-1S	400		I	Self Recording	Diaphragm USG
501.09	250*	PHS-1S	400		I	Self Recording	Capsule & USG Diaphragm (Neg.)
501.09	250	PNS	400		I	Self Recording	Bendix Diaphragm
501.09	250	QGS	1,500		Q IV	Self Recording	Total USG Diaphragm
501.09	250	QGS	400		Q IV	Self Recording	Side-on Capsule
501.10	290	Detroit Control	1,000	720	Q III	FM	4 Arm Strain Bridge
501.10	290	Detroit Control	200	200	Q III	FM	4 Arm Strain Bridge
501.10	290	Microsystems	200	200	I	Miniature	4 Arm Strain Bridge
501.10	290*	Wiancko	200	[illegible]00	I	System D	4 Arm Variable Rductapce
501.10	290	Dynisco	200	[illegible]00	I	FM	4 Arm Strain Bridge
501.10	290	PGS	200		V	Self Recording	Bendix Diaphragm
501.10	290*	PHS	400		V	Self Recording	Capsule
501.10	290	PHS	200		V	Self Recording	Timer, Diaphragm USG
501.10	290	QGS	800		Q IV	Self Recording	Diaphragm USG
501.10	290	QGS	200		Q IV	Self Recording	Capsule Side-on
501.11	325*	Wiancko	500	150	I	System D	4 Arm Variable Rductance
501.11	325	PHS	200		V	Self Recording	Timer, Capsule
501.11	325	PNS	200		V	Self Recording	Bendix Diaphragm

TABLE 2.1 CONTINUED

Station	Distance ft	Type Gage	Range psi	100% Cal. psi	Mount	Recorder	Sensor
501.12	380	Detroit Control	400	280	Q III	FM	4 Arm Strain Bridge
501.12	380	Detroit Control	200	100	Q III	FM	4 Arm Strain Bridge
501.12	380 *	Wiancko	300	100	I	System D	4 Arm Variable Reluctance
501.12	380	PGS	100		VI	Self Recording	Bendix Diaphragm
501.12	380 *	PHS	150		VI	Self Recording	Capsule
501.12	380	PHS	100		VI	Self Recording	Diaphragm USG
501.13	520 *	Wiancko	200	105	Q III	System D	4 Arm Variable Reluctance
501.13	520 *	Wiancko	40	50	Q III	System D	4 Arm Variable Reluctance
501.13	520 *	Wiancko	100	50	I	System D	4 Arm Variable Reluctance
501.13	520	Microsystems	50	50	I	Leach	4 Arm Strain Bridge
501.13	520	PGS	50		VI	Self Recording	Bendix Diaphragm
501.13	520	PGS	50		VI	Self Recording	Bendix Diaphragm
501.13	520	PHS	50		VI	Self Recording	Diaphragm USG
501.14	680 *	Wiancko	40	30	II	System D	4 Arm Variable Reluctance
501.14	680	PHS	50		V	Self Recording	Diaphragm USG
501.14	680 *	PHS	50		VI	Self Recording	Photo Initiator, Capsule
501.14	680	QGS	100		Q IV	Self Recording	USG Diaphragm-Total
501.14	680	QGS	50		Q IV	Self Recording	Capsule Side-on
501.15	830	Detroit Control	100	20	II	FM	4 Arm Strain Bridge
501.15	830	PHS	25		VI	Self Recording	Timer, USG Diaphragm
501.15	830 *	PHS	50		VI	Self Recording	Photo Initiator, Capsule
501.16	920	Wiancko	30	16	II	System D	4 Arm Variable Reluctance
501.16	920	PHS	15		VI	Self Recording	Diaphragm USG
501.16	920 *	PHS	25		VI	Self Recording	Photo Initiator, Capsule

TABLE 2.1 CONTINUED

Station	Distance ft	Type Gage	Range psi	100% Cal. psi	Mount	Recorder	Sensor
501.17	1160 *	Wiancko	40	10	II	System D	4 Arm Variable Reluctance
501.17	1160	Piezo Electric				Camera	Crystal
501.17	1160	Piezo Electric				Camera	Crystal
501.17	1160	PHS	10		VI	Self Recording	Bendix Diaphragm
501.17	1160 *	PNS	15		VI	Self Recording	Photo Initiator, Capsule
501.17	1160	PHS	15		VI	Self Recording	Diaphragm USG
501.18	1400 *	Wiancko	15	7	II	System D	4 Arm Variable Reluctance
501.18	1400	PHS	10		VI	Self Recording	Diaphragm USG
501.18	1400 *	PHS	15		VI	Self Recording	Photo Initiator, Capsule
501.19	1900 *	Wiancko	15	4	II	System D	4 Arm Variable Reluctance
501.19	1900	PHS	5		VI	Self Recording	Diaphragm USG
501.19	1900 *	PHS	5		VI	Self Recording	Photo Initiator, Capsule
501.20	2400	PHS	5			Self Recording	Capsule
501.21	5280	PHS	1			Self Recording	Capsule, Photo Initiator
501.22	10,000*	PHS	1/2			Self Recording	Photo Initiator, Capsule
501.23	Well	PHS	1/2			Self Recording	Photo Initiator. Capsule
	13,000*		-				
501.24	JNCT, Mercury HWY & FRRD	PHS	1/2			Self Recording	PE Capsule
501.24	25,000	VLP	-			Self Recording	PE, Bleed plug, Diaphragm
	Q 20						
501.25		VLP	-			Self Recording	Manned, Bleed Plug, Diaphragm
	56,000		-				
501.26	CP-400	VLP	-			Self Recording	Manned, Screw Plug, Diaphragm
501.26	60,000	VLP	-			Self Recording	Manned, Screw Plug, Diaphragm

TABLE 2.2 CODING, IDENTIFICATION, AND NUMBER OF SELF-RECORDING GAGES

Item	Coding	Identification	Number Used
1	PHS	Pressure, Hayden Drive Motor, Standard, Gage of 1957 Vintage.	23
2	PHS-1S	Pressure, Hayden Drive Motor, Standard, Shockmounted.	10
3	PGS	Pressure, Globe Drive Motor, Standard, Miniaturized Prototype.	5
4	PGS-1S	Pressure, Globe Drive Motor, Standard, Shockmounted, Miniaturized Prototype.	5
5	PNS	Pressure Negator Motor Recorder, Standard, Miniaturized Prototype.	7
6	VLP	Very Low Pressure	4
7	QGS	Q, Globe, Standard	3

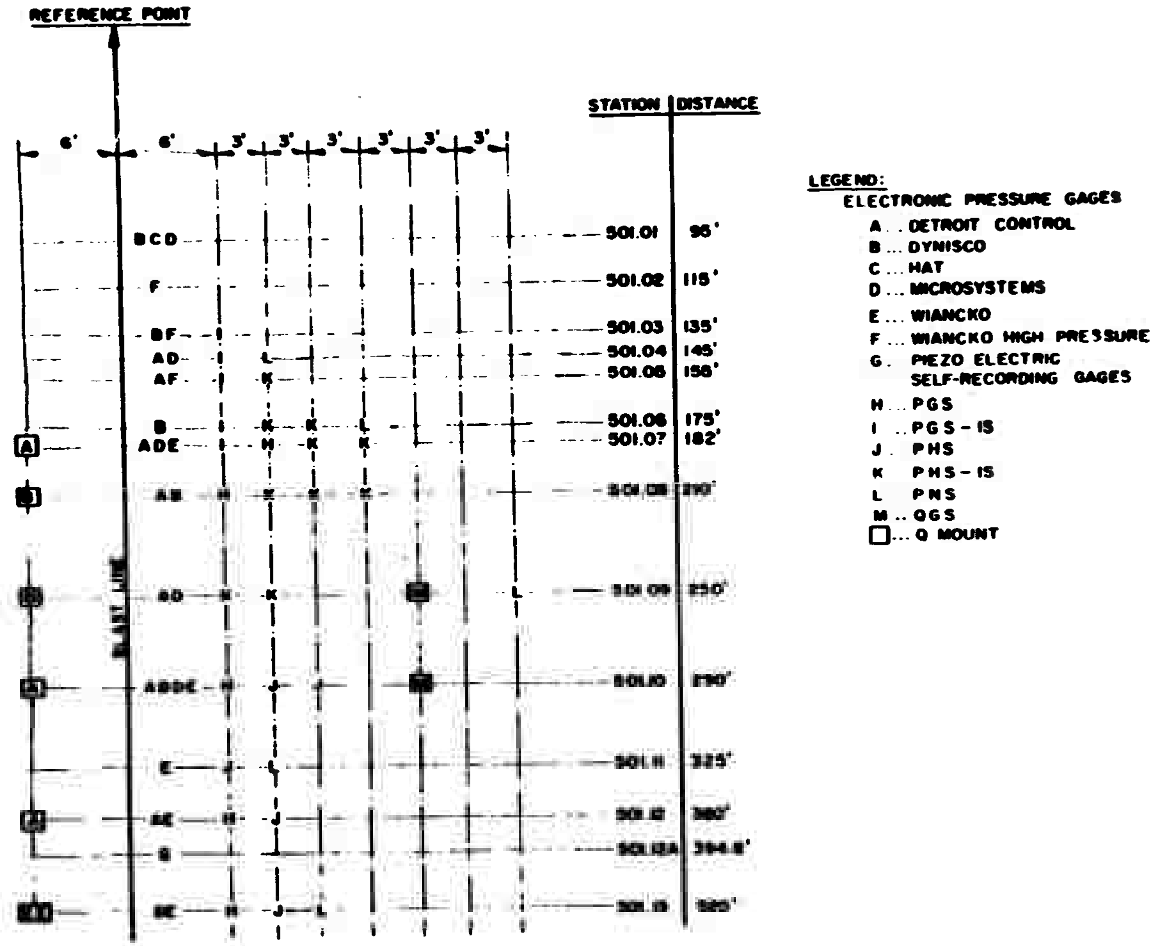


Figure 2.1 Blast line layout.

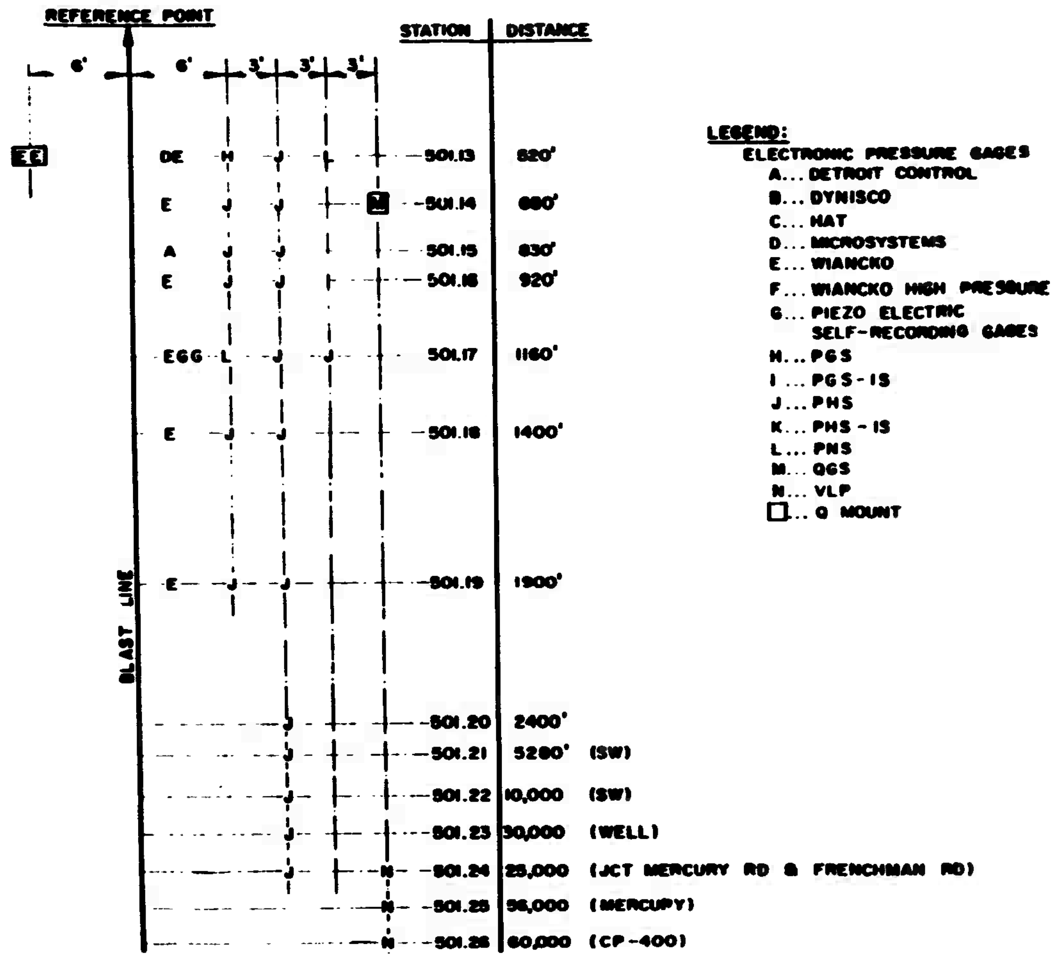
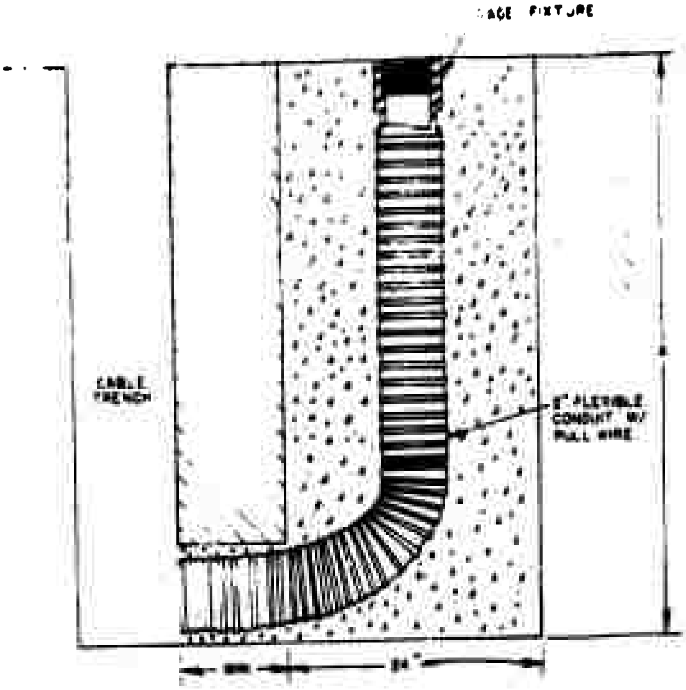
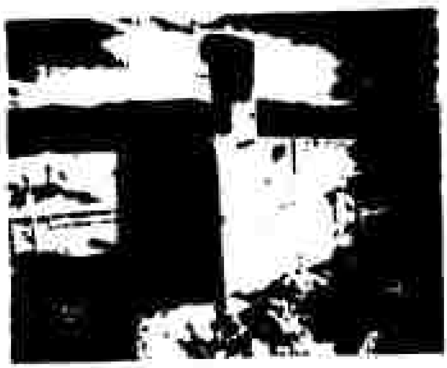
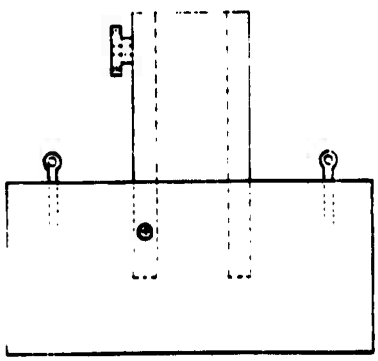


Figure 2.1a Blast line layout (continued).



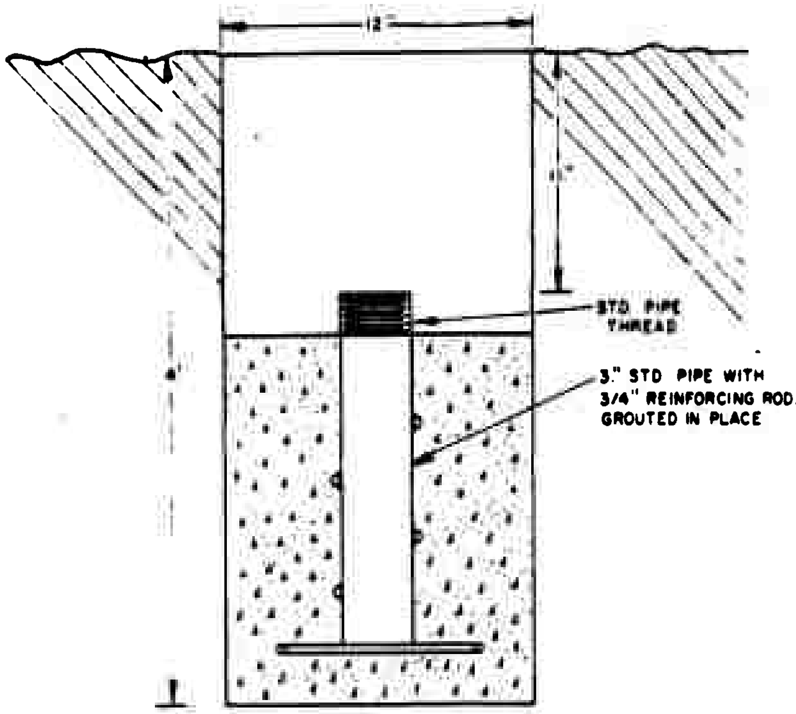
TYPE I GAGE MOUNT (ELECTRONIC) A = 8'
TYPE II GAGE MOUNT (ELECTRONIC) A = 4'



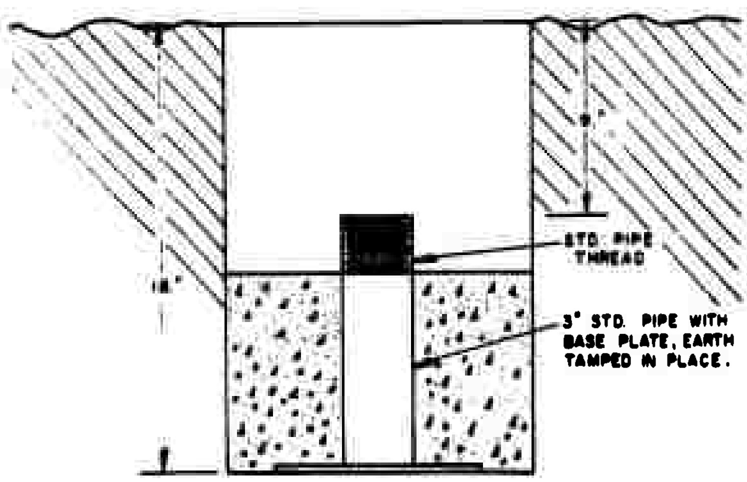


TYPE III GAGE MOUNT (ELECTRONIC)
(WITH PULL WIRE)
TYPE IV GAGE MOUNT (SELF RECORDING)
(WITH SAND FILLED PIPES & TOP ACCESS PORT)

Figure 2.2 Gage mounts, Types I through IV.



TYPE V - GAGE MOUNT (SELF-RECORDING)



TYPE VI - GAGE MOUNT (SELF RECORDING)

Figure 2.3 Gage mounts, Types V and VI.

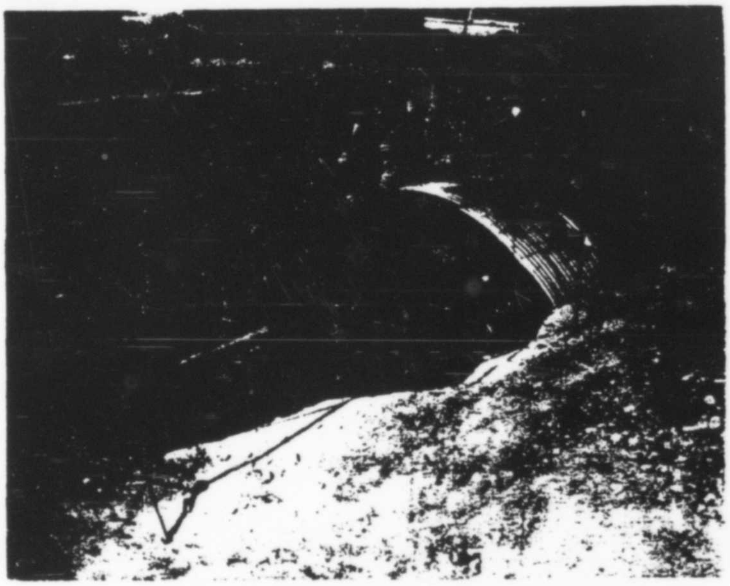


Figure 2.4 Recording shelter construction. (DASA 312-05-NTS-62)

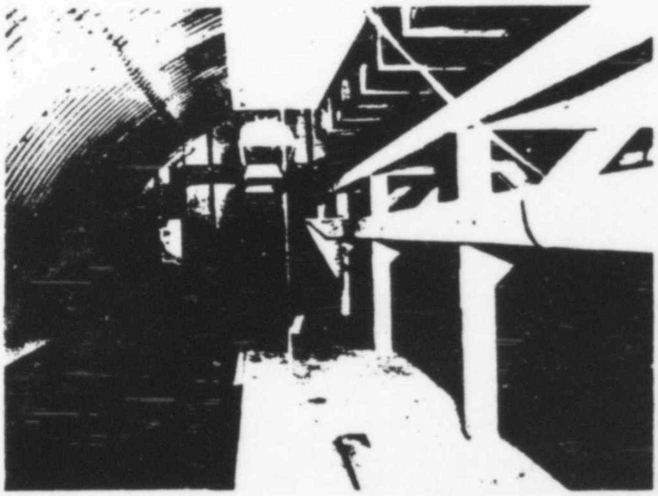


Figure 2.5 View of signal cable shelf, recording shelter. (BRL photo)

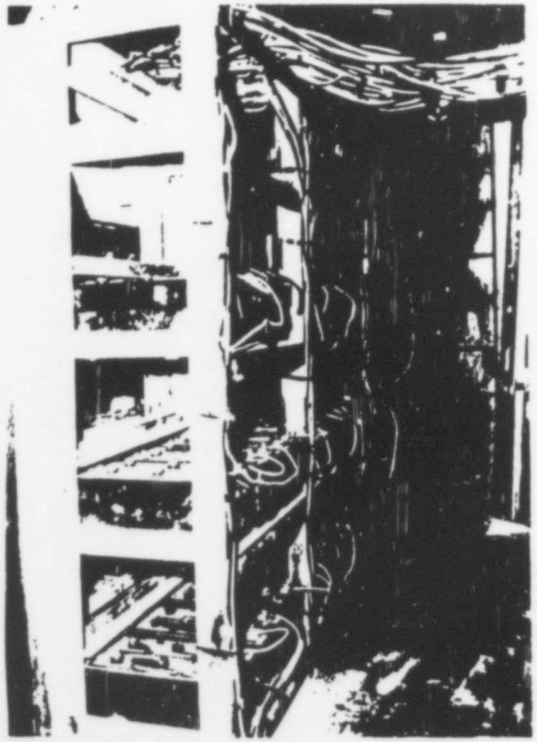


Figure 2.6 View of battery installation, recording shelter. (DASA 555-06-NTS-62)

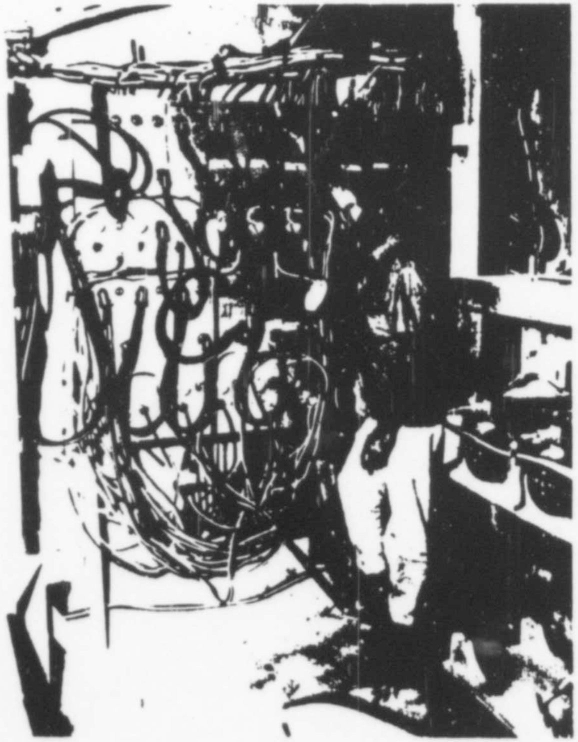


Figure 2.7 View of power-switching panels, recording shelter. (DASA 555-03-NTS-62)

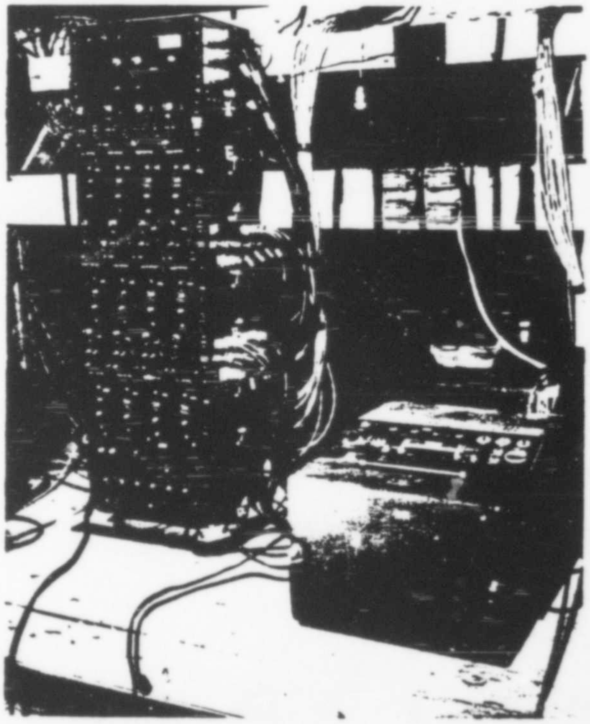


Figure 2.8 View of 3-kc carrier system.
(DASA 555-07-NTS-62)

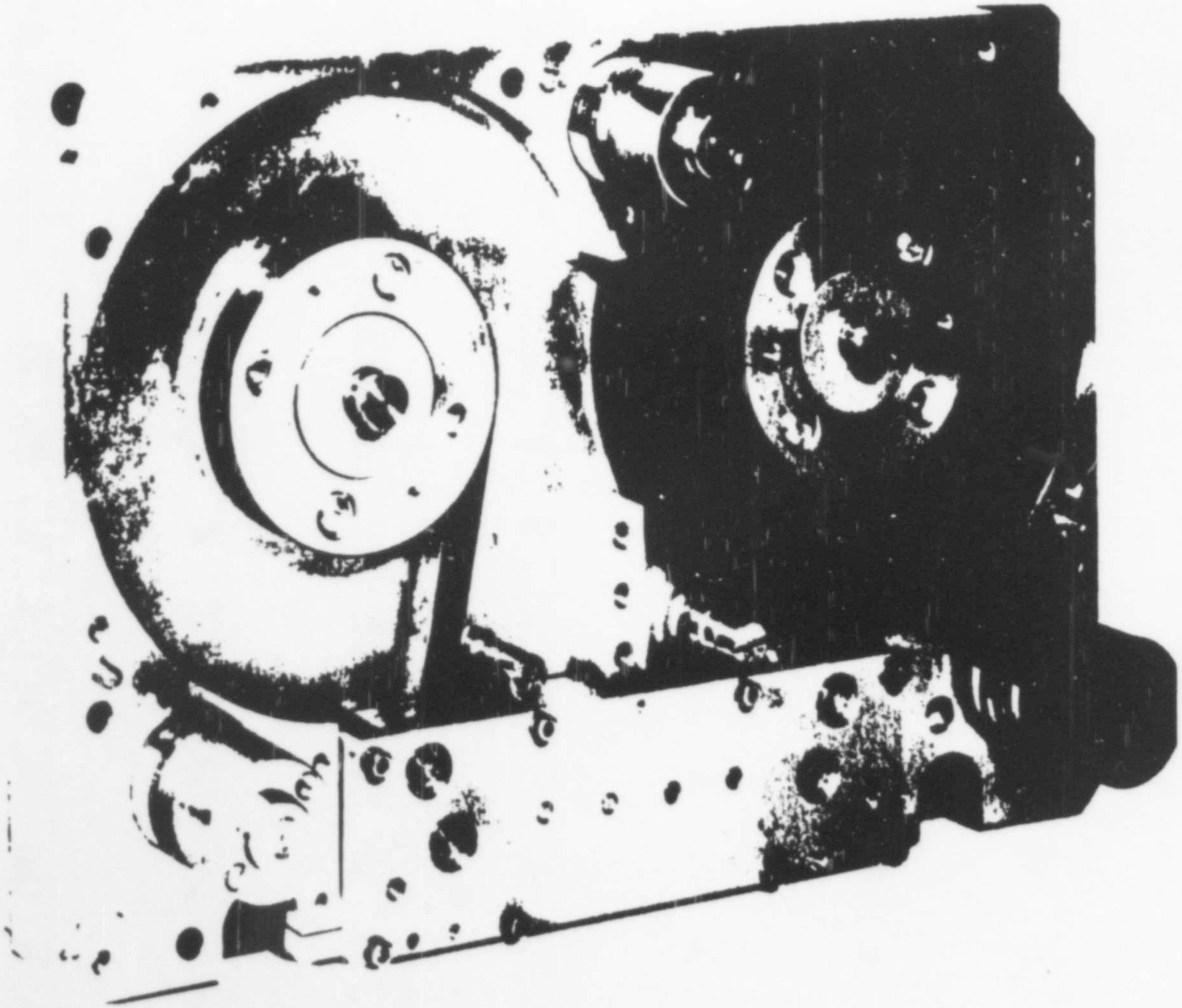


Figure 2.9 Disassembled view of Weber recorder. (BRL photo)

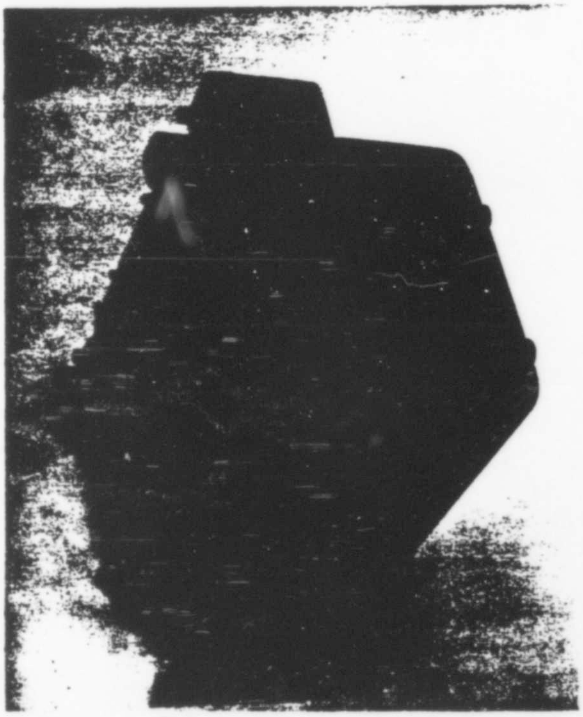


Figure 2.10 Assembled view of Weber recorder.
(DASA 661-06-NTS-62)

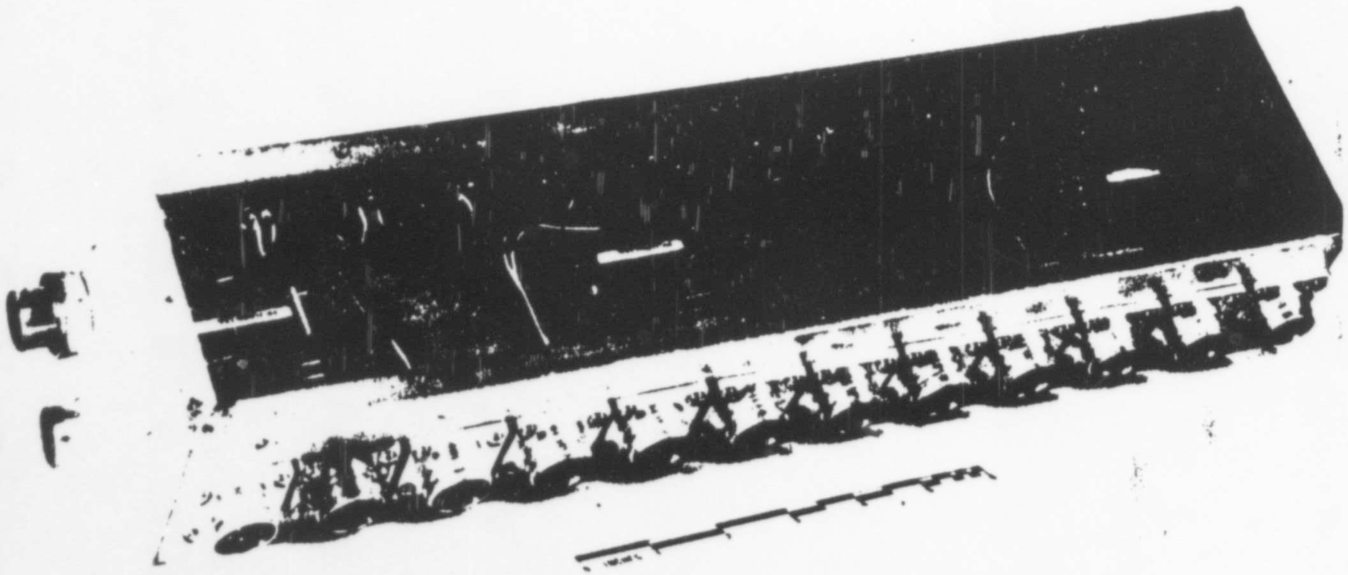


Figure 2.11 Remote-grounding relays. (BRL photo)

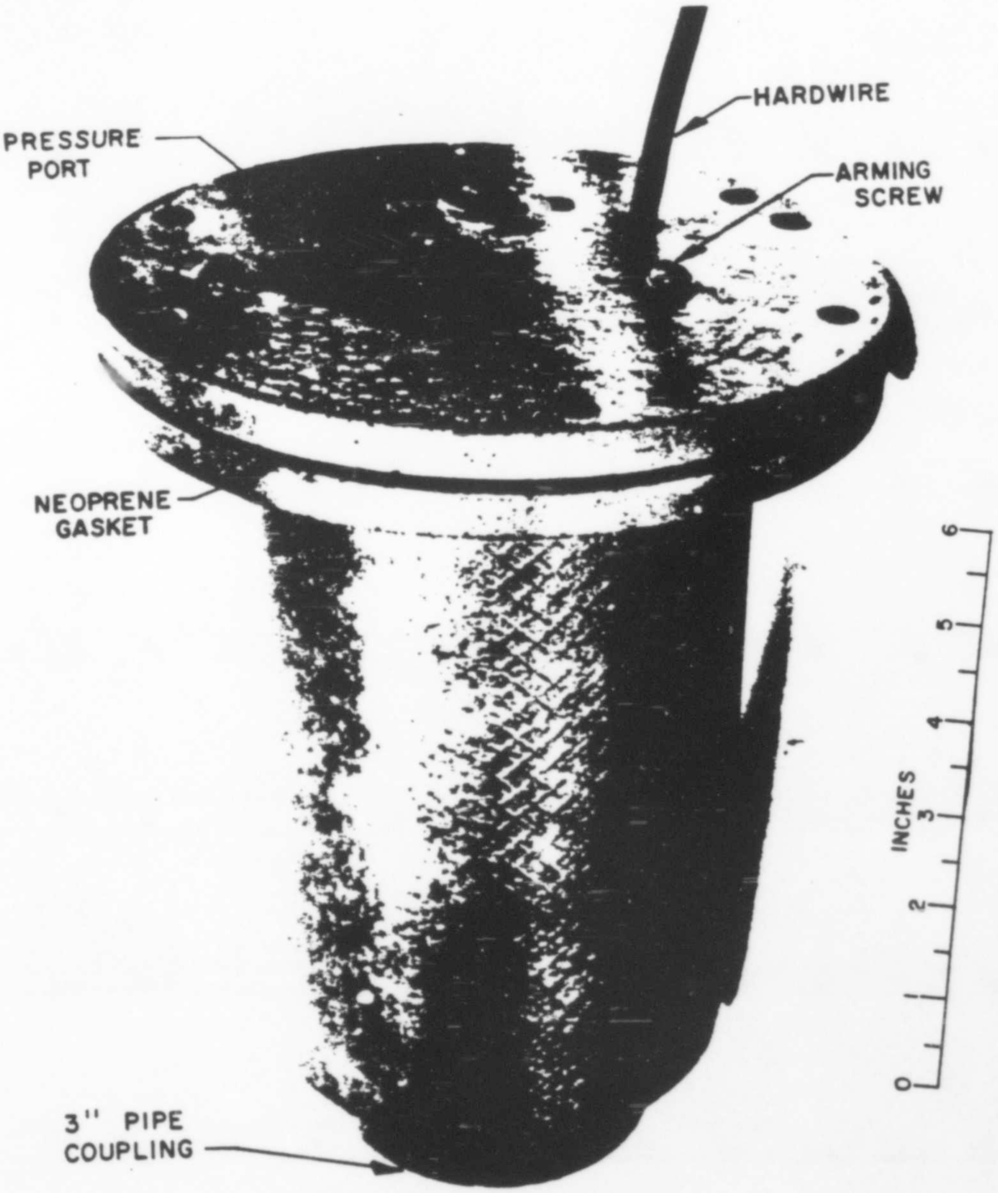


Figure 2.12 Typical self-recording gage. (BRL photo)

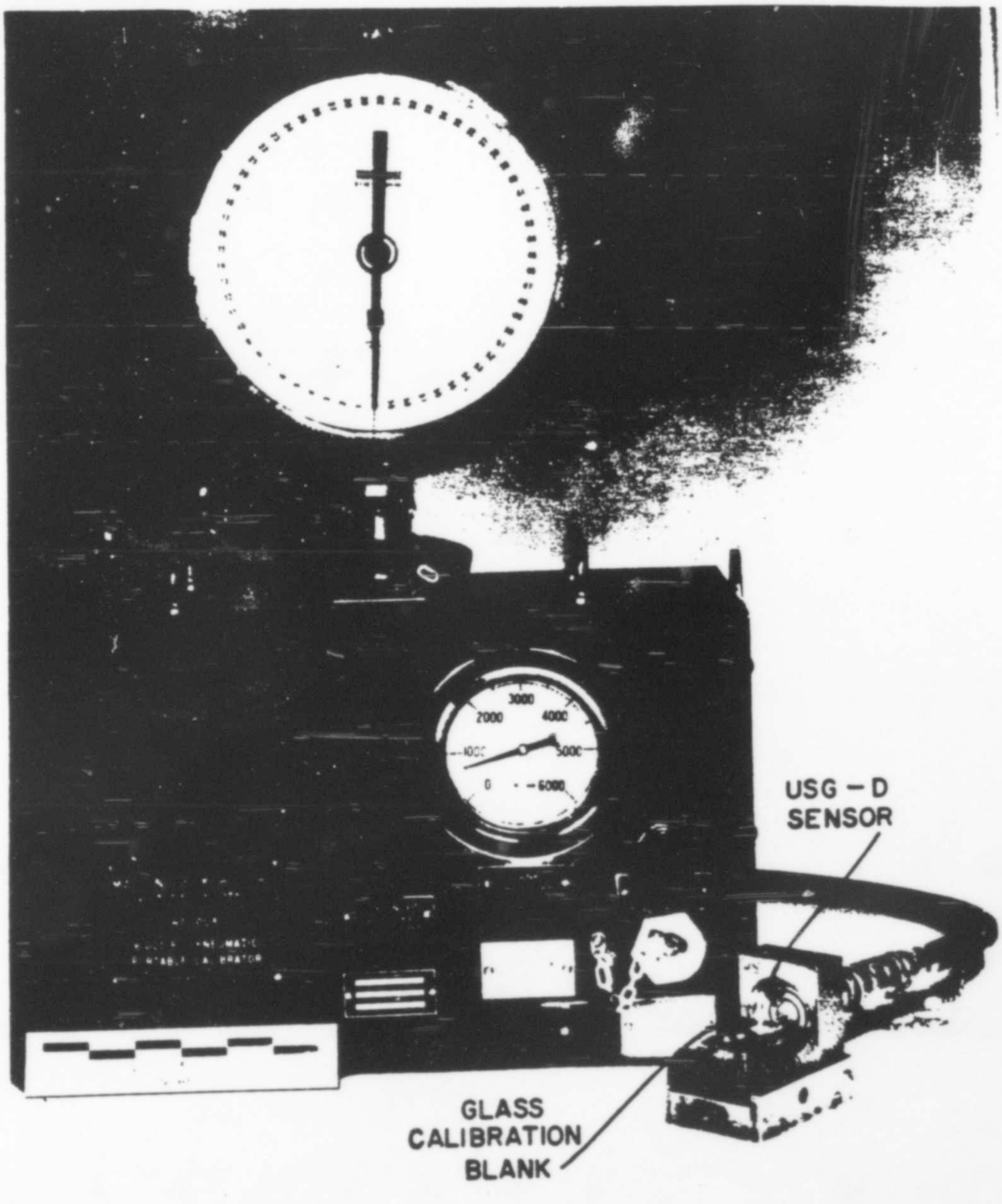


Figure 2.13 Pressure calibrator for self-recording sensors. (DASA 530-09-NTS-62)

CHAPTER 3

RESULTS

3.1 SCALING

It is necessary to normalize airblast data to some standard so that comparisons can be made. The standard which has been established is a 1-kt radiochemical yield at sea-level ambient pressure and 15° C. The following scaling relations have been accepted as standard:

$$S_p = \frac{14.7}{P_o}$$

$$S_d = \left[\frac{P_o}{14.7}\right]^{1/3} \left[\frac{1}{W}\right]^{1/3} = \left[\frac{1}{S_p(W)}\right]^{1/3}$$

$$S_t = \left[\frac{T_o + 273}{288}\right]^{1/2} \left[\frac{P_o}{14.7}\right]^{1/3} \left[\frac{1}{W}\right]^{1/3} = \left[\frac{T_o + 273}{288}\right]^{1/2} S_d$$

$$S_i = \left[\frac{T_o + 273}{288}\right]^{1/2} \left[\frac{14.7}{P_o}\right]^{2/3} \left[\frac{1}{W}\right]^{1/3} = S_t \times S_p$$

Where: S_p = pressure scaling factor

S_d = distance scaling factor

S_t = time scaling factor

S_i = impulse scaling factor

3.2 INSTRUMENTATION PERFORMANCE

3.2.1 Electronic Instrumentation. A large percentage of the electronic data channels recorded on test-proven equipment were successful, whereas, almost all channel failures were instrumented on recorders and transducers that were unproven in a nuclear environment. The instrumentation back-up of recording types proven successful in past nuclear operations allowed Project 1.1 to meet its objectives.

Although data from the new high-response equipment (0 to 10 kc) yielded little blast information, from an instrumentation viewpoint, indications were obtained which give hope for success in future nuclear tests.

Eleven data channel, recording on CEC System D with proven Wiancko pressure transducers, gave good blast line data. Four additional data channels, of a more recent model of Wiancko pressure transducers and recorded with System D, gave unsatisfactory results mainly because of insufficient transducer element damping. Delivery of these transducers was too late to perform evaluation tests before the field test.

The CEC magnetic tape transport failed to operate during the shot because of an intermittent open in the capstan delay circuit. Except for one dry run, the transport performed properly. A thorough investigation of the recorder operation and subsequent individual runs did not reveal the defective part.

After many tests during postshot investigation the intermittent component was singled out and replaced. This restored the recorder to normal operation on all subsequent runs.

The miniature Weber magnetic tape recorder, mainly used for instrument environmental checks for future nuclear work, indicated satisfactory performance on some of its checks and limited performance on others.

The VCO shielding-comparison test showed that the shielded VCO had approximately 3 msec saturation from the EM pulse, compared with 7 msec saturation of the unshielded VCO. The shielded VCO was disturbed in one direction only, whereas the unshielded VCO was saturated in both directions. The oscillator checks showed some disturbances to signal amplitude caused by radiation and/or electromagnetic effects as did the transducer checks. The recorder's resistance to shock effects was excellent in that it played back the preshot calibration records without showing any effects of having been in the shot environment.

The piezorecorder installation along the blast line suffered severe blast damage to its dc-ac converter and sequence timer units.

The Leach magnetic tape recorder apparently was paralyzed by the electromagnetic pulse overloading the electronics to the extent that it yielded only two partial records. A postshot inspection revealed that the voltage regulator transistors had been destroyed.

All transducers were recovered except the BRL Hat gage (Station 501.01), which was missing from its mount. A large percentage of the transducers from Station 501.09 and forward were physically damaged from heat or blast. All Q and total head probes were externally damaged and their internal signal cables charred. Nose-plugs and probe fronts were melted away or fused together. Gage diaphragms on the probe and ground mounts were melted. Wiancko gage rubber shock mounts were charred and their bourdon tubes were eroded.

Indications are that external metal parts were red or white hot while being blasted. The probe located at Station 501.02 was fused to the stinger which necessitated a cutting torch for removal. Generally, the gages were easy to remove. Some difficulty was experienced with the ground mounts containing rusted steel inserts: one high-pressure Wiancko gage was in this category and required a cutting torch for its removal.

Visual and resistance continuity checks of the gages were the only inspections that were practical to make because of their hot condition. The findings of these inspections are shown in Table 3.1.

The signal cables were checked for electrical continuity and shorts. This was accomplished by first identifying the cables by inserting a signal generator signal into the transducer end of the cable and locating the recorder end with an oscilloscope. A multimeter check was given each cable after it was identified.

Charred portions of cable in the mounts were removed to enable checking the remaining portions. None of the underground cables suffered damage because of radiation or EM effects.

Several spark gaps were recovered and examined. In all cases they appear to have arced. Their electrodes were burned and the glass discolored.

3.2.2 Self-Recording Instrumentation. The self-recording gages of the PHS and VLP types performed satisfactorily in their designed ranges. Anticipated gage performance was realized. The cadmium sulfide photocell initiators operated as intended .

The PHS-1S gages received only minor exterior damage in the 1,000 to 1,500 psi region; however, extensive interior damage was sustained by these gages. Those gages in the lesser pressure region performed satisfactorily. Data was obtained from these units.

The PGS gages yielded pressure-time records at three of the five stations. No permanent damage was sustained by any of the gages. The two failures were due to malfunctions in the gage electrical circuit. One gage had a weak battery in the relay circuit, while the second gage had a loose battery connection. The PGS-1S gage, subjected to the extreme environmental conditions of 1,000 to 3,000 psi, shock, and stagnation phenomena for the first time, failed at the base of the gage case. Internal components of the gage were severely damaged by the crushing effect.

The PNS gages produced good records in the pressure region less than 300 psi; in the higher pressure region the gage system failed at several points resulting in a record of peak pressure only or no record at all. At Stations 501.9 and 501.11, the base containing the power supply and the square-wave generator was driven into the gage canister as a result of the shock condition. At Stations 501.4 and 501.6 thermal energy entered the gage through the vellumoid gasket to severely damage the internal components.

The QGS gages located at Stations 501.9 and 501.10 operated and yielded information. The gage at Station 501.14 failed to operate, due apparently to difficulties in the power-pack cutoff mechanism. Chattering of the stylus needle was evident in the deflection time curves and was due to the prevailing shock and vibration conditions. Although no positive indication was evident, it is felt that the filling of the pipe mounts with sand served to dampen the vibration in the mounting system and thus reduce the overall effects on the gage.

3.3 PRESENTATION OF DATA

The blast wave parameters for Shot Small Boy are presented in the form of tables, curves, and pressure time plots. A brief statement in the remarks column of the table indicates the quality of the record at individual stations.

Overpressure measurements were obtained from 0.0185 psi up to 1,640 psi, and the results are tabulated in Table 3.2. The maximum overpressure valves are plotted in Figures 3.1 and 3.2. In the high pressure region, some scatter exists because of the lower frequency response of several gages and the large amount of oscillations superposed on several of the pressure time records.

A nonclassical precursor-type wave was indicated by several gage records, both self-recording and electronic (Reference 1). At 325 feet, a classical blast wave was recorded by all gages. At the next station, 380 feet, the early development stages of a precursor Type II waveform was observed. A 10-millisecond separation existed between the precursor wave and the main wave at 520 feet. By 680-foot distance, separation between the two waves had disappeared, and a rounded Type III precursor wave shape was observed (Reference 2). Beyond 680 feet, classical wave shapes were recorded. Plots of the pressure time records are presented in Appendix D.

At Stations 501.08 and 501.09, the negative phase was measured by self-recording gages using a low range diaphragm and providing a stop to keep the diaphragm from being over-ranged during the positive phase. At both stations the negative phase ended very abruptly. In studying the records and the recalibrations of the diaphragms one would conclude that the gages functioned properly. The rapid return to ambient conditions did not exhibit shock characteristics.

The measured time of arrival of the blast wave was in good agreement with predictions from 300 feet out to 1,900 feet. A plot of the measured data is presented in Figure 3.3. The curve was drawn so it would pass through all the data points.

Positive phase duration versus ground range and positive impulse versus ground range are plotted in Figures 3.4 and 3.5, respectively. The inflection in the positive phase duration curve has been recorded on many shots before but in some cases has been smoothed through. This fast rise in the curve has been observed on many strong precursor-forming shots and understandably so, since the precursor advances rapidly ahead of the main wave thus increasing the positive duration. Most of the scatter in the data is believed to have been caused by heat effects on the gage and by errors in reading the records. Accurate determination of ambient pressure at the conclusion of the positive phase of the high pressure records is extremely difficult due to the range of the element.

Dynamic pressure information was obtained from all standard gages; from the new gages, the information was lost because the new tape recorder malfunctioned. The maximum dynamic pressure measured is presented in Table 3.3. The positive phase duration was lost because of heat effects on the gages. The comparison between the predicted and measured dynamic pressure in Figure 3.6 shows good agreement.

The stagnation pressures are higher than would be predicted based on the measured overpressure but appear to fit an extension of the DASA 1200 curve (Reference 1).

TABLE 3.1 SMALL BOY POSTSHOT INSPECTION (BLAST LINE)

Station	Gage	Serial Number	Recorder	Gage Face	Gage Bridge
501.01	Dyn	12089	Leach	Burned	Open
	MS	143	FM	OK	Open
	Hat	NSN	FM	Gage Missing	
501.02	W	61032	SysD	OK	Damaged
501.03	Dyn	12113	FM	Burned	Damaged
	W	61033	SysD	OK	Damaged
501.04	DC	5722	Leach	Distorted	Damaged
	MS	491	Leach	Burned	Open
501.05	DC	5723	FM	Burned	Damaged
	W	61034	SysD	OK	OK
501.06	DC	5034	Leach	Burned	Damaged
	W	10240	SysD	Burned	OK
501.07	DC	5729	Leach	OK	OK
	W	10252	SysD	Burned	OK
	MS	493	Leach	OK	Open
	DC	5726	Leach	Burned	Shorted
501.08	Dyn	9116	FM	Burned	Damaged
	DC	5249	FM	OK	Damaged
	Dyn	12203	FM	Burned	Damaged
501.09	DC	5250	Weber	OK	Open
	MS	280	Leach	Burned	Open
	MS	490	Leach	Burned	Open
501.10	MS	185	Weber	OK	Open
	W	10176	SysD	OK	Open
	DC	5032	FM	OK	OK
	DC	5725	FM	OK	Open
	Dyn	12202	FM	OK	Open

TABLE 3.1 CONTINUED

Station	Gage	Serial Number	Recorder	Gage Face	Gage Bridge
501.11	W	1941	SysD	OK	OK
501.12	DC	5203	FM	OK	OK
	W	10159	SysD	Ok	OK
	DC	5033	FM	OK	OK
501.13	MS	469	Leach	Burned	OK
	W	10244	SysD	OK	OK
	W	10103	SysD	OK	OK
	W	10257	SysD	OK	OK
501.14	W	10230	Sys D	OK	OK
501.15	DC	5316	FM	OK	OK
501.16	W	A8DF19	SysD	OK	OK
501.17	W	10239	SysD	OK	OK
501.18	W	10133	SysD	OK	OK
501.19	W	10167	SysD	OK	OK

Page 64 deleted.

TABLE 3.3 DYNAMIC PRESSURE RESULTS

Station	Ground Range ft	Type Gage	Maximum Dynamic Pressure psi
501.09	250	Self Recording	813
501.10	290	Self Recording	666
501.13	520	Electronic	80
501.14	680	Self Recording	14.7

Pages 66 through 71 deleted.

CHAPTER 4

DISCUSSIONS AND CONCLUSIONS

4.1 FREE-FIELD BLAST PARAMETERS

The Small Boy event provided the first opportunity to obtain pressure-time data from a small yield device detonated only a few feet above the dusty surface of Frenchman Flat. Other small yield devices have been fired in other areas both at the Nevada Test Site and at the Pacific Proving Ground. For example, Shot Sugar during Operation Buster-Jangle was fired near the surface in Yucca Flat at NTS. The surface in this area is a loose gravel soil, in contrast to the fine powder dust over the hard, dry lakebed of Frenchman Flat.

A comparison between the 1-kt near-ideal curve taken from Reference 1 and the scaled Small Boy overpressure data is shown in Figures 4.1 and 4.2. The scaled data for all the measured parameters are tabulated in Table 4.1. The scaled overpressure values agree quite well with the 1-kt curve. The curves have been dotted above 200 psi, since this is the highest predicted in Reference 1. Below 5 psi, a straight line appears to best fit the data. Overpressure measurements made on Shot Sugar agree with the Small Boy data, except in the 1- and 2-psi region.

The arrival time data agrees well with the past data for near-ideal conditions. The relatively short-lived precursor wave had very little effect on the arrival time versus distance curve as shown in Figure 4.3. Good agreement exists between the predictions and measured positive durations in the low pressure region; in the high pressure region, it is difficult to ascertain the time at which ambient pressure is reached. As a result, in the high pressure region a large amount of scatter exists in the data (see Figure 4.4).

The total positive impulse measured agrees well with the predictions. An extension of the information from 4,000 psi-msec to 8,000 psi-msec was obtained, as shown in Figure 4.5. Since the positive impulse represents the total pulse of the blast wave, it is gratifying to see the good agreement between the Small Boy data and the data from past nuclear shots.

4.2 NONCLASSICAL WAVEFORMS

Nonclassical shock waves have been measured in a large number of shots on various nuclear operations, both at the Nevada Test Site and the Pacific Proving Ground. It was not realized at first that this nonclassical wave shape was caused by a wave, now called the precursor, advancing ahead of the main shock wave. During Operation Tumbler this nonclassical phenomenon was defined, and since then, many reports have been written and several prediction techniques published. Criteria for precursor formation are shown in Figure 1.2.

The effect of a strong precursor is to distort the shock wave by increasing its duration, reducing the peak pressure and degrading the rapid rise time of the shock front. It has been observed that the wave shape changes with increasing distance from ground zero. The wave shape close-in has the classical exponential decay and can be predicted from classical theory. As the distance increases, the precursor, or front porch ahead of the main wave, continually increases until the main pressure pulse has disappeared and only a round compressional-type wave is observed. As we increase in distance we see this compressional-type wave change back into a classical wave. This change from classical conditions to nonclassical and back to classical has been referred to as the precursor cycle. Large variation in waveforms that have been observed follow a definite pattern and, when scaled, appear to fall into a logical pattern. Several empirical prediction methods have been devised to predict the waveforms for various distances from ground zero.

Shot Small Boy of Operation Sun Beam produced precursor waveforms at several stations. The Small Boy wave shapes are compared in Figure 4.6 with the wave shapes from other low yield shots.

4.3 INSTRUMENTATION DISCUSSION AND RECOMMENDATIONS

4.3.1 Electronic Instrumentation. The majority of channel failures of the electronic instrumentation were caused by the severe environmental effects. Greater measures must be made to combat these effects. Solutions or aids to lessen or eliminate some of the environmental effects on electronic recording equipment are suggested as recommendations and are actually measures being investigated by BRL to increase their capability of making electronic measurements at close-in stations of nuclear tests.

a. Radiation:

Investigation and reactor tests to determine the threshold of deleterious effects on transducers and electronic modules to enable requirements for sufficient burial depth or shielding to be determined as based on predicted radiation levels.

b. Thermal:

Use of a more heat-resistant or thicker metal in transducer diaphragms and mounts in addition to ceramic coatings if necessary. Spalling of transducer diaphragms during recording may affect the accuracy of results; however, a partial or interpretable measurement may be obtained before diaphragm rupture. Remotely cooled transducers hold promise of a means to combat thermal problems. Insulation of signal cables with asbestos covering is also being investigated.

c. Electromagnetic Pulse.

Possibly the severest environmental cause for channel failure is the electromagnetic pulse affecting the recording electronics. It is believed that this pulse is introduced into the recorders from the external (antennas) signal cables. It is recommended that future field installations for nuclear tests of systems and cables be enclosed in ungrounded triple shielding with limited distances between the transducer and recorder. It is recommended that for future data acquisition system installations for nuclear testing, further consideration should be given as to methods of protection against the electromagnetic pulse and the radiation environment. Aside from the spark gaps and signal grounding relays, as used in the past, one other protection method will be investigated on Operation Ferris Wheel. It will consist of ungrounded triple shielding with limited distances between recording systems and transducers.

d. Shock and Blast

Instruments and instrument container capabilities to withstand shock and blast should be determined to insure designs offering sufficient protection to withstand the predicted levels.

4.3.2 Self-Recording Instrumentation. The self-recording instrumentation employed on the test is evaluated in Table 4.2. A great deal of useful information pertaining to the design of future gages was obtained. The simple diaphragm BDX sensor indicates a higher response capability than previously obtained (natural frequency equal to or in excess of 2,200 cps), with the inherent features of a single diameter for all ranges and an integral guide to limit lateral motion of the stylus arm. Miniaturized recording systems of the negator spring and the dc motor type indicated a potential usefulness for pressure measurements in the 0- to 600-psi regions. Shock-mounting of the dc motor type miniature gage will extend the range of the gage to 2,500 psi. Although the miniature shock-mounted gage failed at the base of the canister, data was obtained to guide further design activity. Standard gage systems, consisting of the Hayden drive motors, continued to function well at the majority of positions where they were located.

Pages 77 and 78 deleted.

TABLE 4.2 EVALUATION OF SELF-RECORDING INSTRUMENTATION

	Performance	Recommendations
A. Sensors		
1. Capsule	Satisfactory	Discontinue general use due to slow response characteristics.
2. USG-Diaphragm	Satisfactory with reservations	Discontinue general use. Installation and setup difficulty with no integral stylus guide.
3. BDX-Diaphragm	Satisfactory with reservations	High response capability, single size for all ranges & integral stylus guide recommend for general use. Modify by soldering to a mounting ring for easy installation in gage with use of O-ring.
B. Gage System		
1. PGS-1S	Unsatisfactory, failure of the canister at the base	Redesign of the shock isolation system, canister, and the field mounting arrangement
2. PGS	Satisfactory	Minor modifications
3. PNS	Satisfactory in pressure regions less than 300 psi. Unsatisfactory in pressure regions greater than 300 psi due to canister design.	Major modification in canister design. Minor redesign in initiation system.

TABLE 4.2 CONTINUED

B. Gage System	Performance	Recommendations
4. PHS	Satisfactory in pressure region less than 200 psi	Phase out of service in favor of miniature gages using BDX sensors
5. PHS-1S	Satisfactory in pressure region less than 800 psi	Phase out of service in favor of PGS-1S gage.
6. PHS-1S with Negative Pressure Sensor	Satisfactory	Favor utilization of single gage with single sensor
7. QGS	Satisfactory with reservations	Modify to utilize the BDX sensor for stagnation and side-on pressure. Redesign power pack and cutoff mechanism
8. VLP	Satisfactory	Redesign to improve overall characteristics
C. Accessory Components.		
1. Square-Wave Generator	Satisfactory in low pressures, unsatisfactory at high pressure levels	Redesign system for 200-cycle output for operation under high g loading
2. Photoinitiator	Satisfactory	New solid-state devices make system obsolete

Pages 81 through 86 deleted.

Appendix A

ELECTRONIC AND SELF-RECORDING INSTRUMENTATION

Louis Giglio-Tos and Daniel P. Lefevre

A.1 ELECTRONIC RECORDING SYSTEMS

A.1.1 System D, CEC. System D is an amplitude-modulated, suppressed-carrier system capable of recording static and dynamic transducer outputs, with a frequency response of 0 to 600 cps. This system may be used with two- or four-arm bridge transducers operating on the strain (resistance change) or variable reluctance principle. A signal of ±1 mv will cause a full-scale deflection. Attenuators enable the system to operate with input signals in the range of +1 volt to −1 volt. The system includes an oscillator power supply for transducer excitations with an output of 10 volts at 3 kc, an attenuator to vary the input signal levels, an amplifier to boost low signal levels, and a phase-sensitive demodulator to provide correct polarity to the signal output. Under the condition of zero forcing function on the transducer, the output signal amplitude is zero. The signal amplitude varies from zero to maximum as the forcing function applied to the transducer changes from zero to maximum. The modulated carrier from the transducer is presented to the attenuator, then it is amplified and admitted to the demodulator, where the carrier is decoded and the proper sign and magnitude given to the signal. This output is transmitted to a current-sensitive galvanometer (an oscillographic recorder), where a permanent graphic record of the signal is made on photosensitive paper. The electronic coupling units developed especially to extend the range of the internal System D adjustments, necessary for long signal cables used in field tests, are thoroughly discussed in Reference 3. Likewise, the logic units used for remote control of System D operation are discussed in Reference 3.

A.1.2 CEC Tape Recorder. The CEC recorder consists of a Model 5-702 tape transport, using modular record amplifiers and voltage-controlled oscillators (VCO's). The system has a capacity of 13 data channels and 1 reference (timing) channel. The input sensitivity of the VCO's is ±1 volt minimum to ±10 volts maximum for full-scale deviation (±40 percent of 54 kc). The frequency response of the system is 0 to 10 kc, when the transport is recording at 60 in/sec. This system was intended to be used in a recording shelter where the environmental conditions of blast phenomena are attenuated by a large factor. Since the input signals required are relatively high (±1 volt), a low signal conditioning and amplifying network was necessary. A unit with the following parameters was purchased from the Electro-Mechanical Research Corporation (EMR):

a. A variable dc voltage transducer power supply for each channel with a usable range of 5 to 20 volts.

b. A balancing network for each channel to zero-null any transducer unbalance in the range of 0 to 60 mv.

c. A dc amplifier for each channel with a gain of 1,000, thus allowing a ±mv signal input to give a ±1 volt output.

d. A logic unit for complete remote control for all phases of the recording cycle.

Under the condition of zero forcing function on the transducer, the input to the dc amplifier is zero. As the signal magnitude varies from zero to maximum, the amplifier follows the pattern and its output goes to the VCO and record amplifier, then to the record head, and finally on the tape. The playback is achieved by a separate ground unit which has capabilities of FM signal discrimination and amplification. The current amplifier output is transmitted to a current-sensitive galvanometer (an oscillographic recorder), where a permanent graphic record of the applied signal is made on photosensitive paper.

A.1.3 Leach Miniature Tape Recorder. The Leach tape recorder is a ruggedized, waterproof, shock-mounted data acquisition system. It is intended for use where ground shock is less than 100 g. Installation of the cylindrical shaped ($6\frac{1}{2}$ feet by 10 inches) recording capsule is accomplished by lowering it into an augered hole in the earth and connecting the transducer and control cables. Easy access for removal is retained by covering the top of the capsule with sandbags. Internal batteries provide the necessary power for operating the electronics for 30 minutes and the tape transport for 2 minutes. Thirteen data channels are provided, the fourteenth is used for reference timing and time zero recording. Transducer excitation voltage provided by the system consists of dc, 3, 10, and 20 kc at 10 volts. Ten-kc data response is provided when dc excitation is used, by means of wide-band FM (± 40-percent deviation) with 54-kc center frequency. Noise levels are on the order of 10 percent. Playback is achieved by employing the same ground unit used for the CEC-EMR tapes.

A.1.4 Weber Miniature Tape Recorder. The Weber tape recorder was designed for data acquisition under adverse environmental conditions. It is intended to be used close-in on blast tests in order to eliminate lengthy signal cables. Its weight of 28 pounds, including the battery pack, and size (7 by 8 by $12\frac{1}{2}$ inches) makes it very portable. The system has a unique cobelt tape drive and transport design which eliminates many problems inherent in tape transports using reels and pinch rollers. Another advantage is the ability to keep the tape-to-head contact constant. The system comprises seven channels: six data and one reference. The data channels are wide-band FM (± 40-percent deviation) with 54-kc center frequency, thus giving a frequency response of 0 to 10 kc. The minimum input to the VCO for full-scale deviation is ± 250 mv. Thus, a high output transducer may be used directly into the VCO and give full-scale deviation without the use of a preamplifier.

Another advantage of this recorder is its ability to operate with the center frequency shifted, thus giving a much higher signal-to-noise ratio when using the extended frequency band. The Fairchild dc amplifiers incorporated in this system may be driven by low signal output transducers. With these amplifiers, a signal of 2 mv will drive the system to full-scale deviation.

A.2 AUXILIARY EQUIPMENT

A.2.1 Time Zero. The time zero electrical pulse for the System D recorders originated from two paralleled solar cells. The output of these cells was distributed to each oscillograph through a time-zero box. The distribution box was designed to operate eleven channels of CEC Model 7-323 galvanometers (see Figures A.1 and A.2). The magnetic tape recorders coupled a solar cell through a pulse network. The output pulse at time zero was superimposed on the reference channel (timing channel).

A.2.2 Timing. Timing signals were recorded directly by galvanometers in the oscillographic recorders. The signals were furnished by Hewlett Packard audio oscillators which were set and locked at a frequency of 1 kc. Outputs of each oscillator were alternated by a 2,000-ohm resistor to prevent overdriving associated galvanometers. The resistor also increased the input impedance to over the 600 ohms required by the oscillator to prevent overloading. Timing displacement on the recording oscillographic paper was adjusted to a desired $\frac{1}{4}$-inch peak to peak with the oscillator gain potentiometer.

The magnetic tape systems utilized their internal 100-kc reference frequency recorded on a separate channel, to establish a timing signal. During playback, this frequency was amplified and fed through a divider circuit with a 100:1 ratio, thus giving an output of 1-msec pulses. The pulses were accentuated every 5 msec and doubly accentuated every 10 msec on the final oscillographic record display.

A.2.3 Electromagnetic Pulse Protection. Protection against the electromagnetic (EM) pulse effects for System D was partly accomplished by shunting 600-volt, 0.1-μf condensers from each end of the oscillator transducer power supply output transformer to the center tap ground. Thus, EM pulses occurring on the carrier lines would be shunted to ground. Another method of protection used with all recorders employed a spark gap at the transducer end of the cable. One end of the spark gap was soldered to the shields, whereas the other side was connected to a ground rod at the bottom of the cable ditch. The spark gaps were set to ionize at 750 volts; thus, when the EM pulse voltage on the shield increased to over 750 volts, it was shunted to ground. The signal-carrying conductors at the shelter end went to relay contacts, which at −2 seconds were remotely shorted to the system ground (see Figure A.3). The relays remained in this mode until the blue box relay opened the power to the coils of the grounding relays. Therefore, the relay delay time allowed the EM pulse on the signal wires to ground to the system, common ground. The Leach and Weber tape recorders did not employ the relay grounding system.

A.3 TRANSDUCERS

The terms transducer and pickup, as applied to instrumentation, denote devices in which the applied forcing functions or stimulus (in this case pressure or acceleration) produces mechanical motion which is converted into an electrical signal. The signal or displacement is proportional to the quantity of the stimulus applied and is referenced to time in the recorder. The transducer designs and operation discussed are based on mechanical and electrical arrangements pertaining to each manufacturer (see Table A.1).

A.3.1 Dynisco (Pressure). The Dynisco pressure transducers (Model PT76) are bonded strain gages, having four active arms electrically connected as a wheatstone bridge. The strain elements (arms) are bonded to a thin-walled cylinder, with one end secured to the case and the other attached to a flat diaphragm. By compressing the diaphragm, the cylinder and its attached gages are strained. This unbalances the bridge, and a signal output results. This configuration is less sensitive to temperature drift than those with sensing elements attached directly to the diaphragm. The low sensitivity, 2-mv output per volt input for full-scale deflection usually requires strain-gage conditioning equipment and preamplifiers to gain sufficient signal for recording. These transducers have a high natural frequency, which results in a high-response capability. The Dynisco Model PT76 is shown in Figure A.4.

A.3.2 Hat (Pressure). The Hat gage is manufactured by BRL and is a one-active-arm strain type bonded on the inside of a closed cylinder. Since this type of transducer is prone to have a large zero shift (for a calibration with a duration of an extended period of time), three passive arms were added at the transducer to electrically form a wheatstone bridge, making the calibration more linear and aiding in stabilizing the drift. The sensitivity of the transducer was 7,106.6 psi/ohm. Upon depressing the cylinder, a change in resistance occurs, thus unbalancing the network and resulting in a signal output.

A.3.3 Micro Systems (Pressure). The pressure transducer (Model P03) employs solid-state elements as strain gages. It has a miniature housing enclosing four active solid-state strain elements bonded directly to its diaphragm and electrically connected to form a wheatstone bridge. An advantage of this transducer is the high sensitivity of approximately 50 mv/volt under full-scale forcing function. The main disadvantage is the large thermal zero shift. This thermal drift is minimized if the available transducer driver is utilized. However, 28-volt dc excitation is required when using the driver. Thermal drift is also minimized if the transducer is allowed to warm up for 15 minutes and the ambient temperature remains constant or fluctuates very slowly. A stimulus on the diaphragm results in bridge unbalance, and a signal results (see Figure A.5).

A.3.4 Norwood Controls (Detroit Control) (Pressure). The Norwood Controls pressure transducers (Model Nos. 111-3-10-34-61) are bonded strain gages having four active arms electrically connected as a wheatstone bridge. The strain elements (arms) are bonded to a thin-walled cylinder, with one end secured to the case and the other attached to the diaphragm. By compressing the diaphragm, a strain is put on the cylinder and transmitted to the strain gages bonded to it. This unbalances the bridge, and a signal output results. These transducers are less sensitive to temperature than those with sensing elements bonded directly to the diaphragm. The output of the transducers is low (2 mv/volt for full-scale forcing function). The low sensitivity usually requires amplifying equipment to make them usable. A high natural frequency results in a high frequency response capability (see Figure A.6).

A.3.5 Wiancko (Pressure). The variable reluctance pickup manufactured by the Wiancko Engineering Company employs coils would on a core, usually of an E-shape configuration. A permeable metal armature fastened to a twisted bourdon tube (gage sensing element) is placed a few thousandths of an inch away from the E-core and coils. The sensing element drives the armature in a rotational fashion when subjected to a stimulus. This movement varies the air gap size and thus varies the magnetic path. Variations of the gaps determine the amount of unbalance, in turn varying the signal output. The transducer requires ac carrier and inherently gives low frequency response. The transducer cavity fill time also lowers the frequency response (see Figures A.7 and A.8).

A.3.6 Statham (Accelerometer). The Statham accelerometer employs a seismic mass attached to an armature held by cantilever flexure plates. The plates restrain the armature to a single degree of motion (approximately). The wheatstone bridge strain gages are attached between a fixed plate and the end of the cantilever flexure plates. As the mass is subjected to motion, the bridge becomes unbalanced, resulting in a signal output (see Figure A.9).

A.4 SELF-RECORDING INSTRUMENTATION

A.4.1 Pressure Sensors. Three types of corrugated diaphragm sensors, shown in Figure A.10, were used in the various gages. The standard sensor is shown in Figure A.11a. This unit consists of two corrugated nestled diaphragms welded together at the periphery; a mounting base with an orifice is attached on one side and a stylus arm with an osmium-tipped recording needle on the other. Ranges cover a pressure level of 0.5 to 1,000 psi. They are designated in this report as the USG (United States Gage Company, manufacturer) sensor or capsule. Mounting is accomplished by inserting the base with O-ring seal into a small recess. Three small screws hold the capsule in place.

Two types of single corrugated diaphragm sensors were utilized. The one unit consists basically of the top shell of the USG sensor and is designated as the USG-D (United States Gage Company, manufacturer) diaphragm sensor; see left side of photograph, Figure A.10. Ranges of this type cover a pressure level of 1 to 1,500 psi. In use, a contour plate with an orifice is mounted between the gage and the sensor. A contour has been machined in the under side of the plate to follow the corrugations of the diaphragm and thus reduce the volume to a minimum. A stylus guide is used to reduce lateral motion. Mounting is accomplished by laying the diaphragm against a seat in the base of the threaded recess. The sensor is secured by screwing a threaded ring against it.

The second type of single diaphragm is shown in the center of Figure A.10. The stylus arm has been restricted to movement in a single plane. These units cover a pressure range of 2 to 3,000 psi. One distinct feature is the standard overall dimension of $1\frac{1}{4}$ inch for all ranges. These units, illustrated in Figure A.11b, were being field tested for the first time. They are designated as the BDX (Bendix Freiz, manufacturer) diaphragm. Mounting is accomplished by laying the sensor against a seat in the base of a recess. A flanged retaining ring is used to hold the diaphragm in place.

A detailed comparison of the characteristics of the various sensors is presented in Table A.2.

A.4.2 PHS Gage. The self-recording PHS gage shown in Figures A.12 and A.13 is the modified version of the gage that has been used successfully in low- and moderate-pressure regions on past nuclear tests. It utilizes the capsule-type sensor mounted on the flange of the gage unit. (A fixed reference stylus is mounted 180 degrees to the capsule.) A chronometrically governed A. W. Hayden Company dc motor drives a recording disk through a turntable and bearing-housing system to record the deflection of the sensor. The recording disks used are aluminized glass or vapor-honed stainless steel. The disks are centered on the gage turntable with the coated side down by a nylon cone and held in position by a neoprene-ring coated retainer. Interchangeable motors of 3, 10, or 20 rpm use a miniature coupling between the turntable and the motor.

Gage initiation employs a timing signal input cable (hard-wire) or a cadmium sulfide photocell (CDS). The CDS cell is placed in series with a 45-volt B battery and sensitive relay. Incident light from the detonation striking the cell through a lucite rod transmitter provides the initiation signal at zero time. Figure A.14 shows the details of the cell assembly. A neutral density coating sprayed on the window of the cell during manufacture governs the cell sensitivity and insures against preinitiation. The hard-wire input cable is used in parallel with the CDS cell or in place of the cell.

A star-gear, cam-operated, cutoff switch operated by the rotation of the turntable controls the number of revolutions that the turntable may make. Operating times of 6 to 80 seconds are possible, depending upon the rpm of the motor used. A microswitch closure produced by an arming screw places the gage initiation system in a ready state. A check for preinitiation can be made external to the gage with the aid of an ohmmeter. This can be accomplished by placing an ohmmeter across common ground (the gage case) and the green lead of the hard-wire cable. If the circuit is closed, the gage may be reset by replacing the ohmmeter with a power supply, which will drive the turntable and star gear cam past the cutoff position. This action opens the checkout circuit and the gage is again ready for a record run. Figure A.15 presents a schematic of the gage circuit.

The gage case is constructed of a 9-inch length of standard 5-inch pipe closed at the bottom with a 3-inch pipe cap welded to it. A $\frac{1}{2}$-inch flange, with a 5-inch inside by $8\frac{1}{4}$-inch outside diameter, is welded to the top. In use, the gage unit is bolted to the top of the flange with a neoprene gasket, $\frac{1}{8}$ inch thick, used to provide an airtight seal. The sensitive relay, power supply, and motor power supply are mounted on a sheet metal base and coupled to the base of the gage frame with an amphenol blue ribbon connector.

For the single diaphragm, USG-D type, the basic PHS gage was used, with a modified frame and flange to allow installation of the sensor and contour plate. The gage is shown in Figure A.16.

A.4.3 PHS-1S Gage. The PHS gages of both the capsule and diaphragm series were shock-mounted as illustrated in the schematic shown in Figure A.17. Barry Controls, Inc. of Watertown, Massachusetts, performed the design and fabrication of these systems under contract to BRL.

The system consists of rubber isolators being placed in five positions between the gage frame and the isolation container. The gage flange was suspended on four equally spaced isolators. The fifth and largest was located between the gage flange and the system top plate, encompassing the pressure orifice. The container was fabricated of cast aluminum, while the top plate was fabricated of stainless steel. A 3-inch-diameter female pipe thread was located on the base of the container to facilitate field installation. Pressure reached the gage sensor through an orifice extending through the top plate and rubber isolator. O-rings were used to seal the top plate, isolator, and gage flange. A blaze-orange fluorescent paint was used in an effort to make recovery operations easier.

A modified PHS-1S gage incorporated a second pressure sensor designed primarily to record the negative phase of the pressure-time curve in the high-pressure region. Pressure was fed from the gage pressure post via a tube to an adapter which mounted a 15-psi USG-D diaphragm. The positive deflection was restrained to approximately 0.010 inch. As the wave decayed, the positive duration and negative phase were recorded with an accuracy impossible to obtain with a high range sensor. Photographs of the system are shown in Figures A.18 through A.20.

A.4.4 PGS Gage. The PGS gage shown in Figures A.21 and A.22 uses a governed dc motor, manufactured by Globe Industries, to drive the turntable and disk assembly. It differs widely in construction and components from the standard PHS gage shown in Figure A.12, yet utilizes the same basic principles of sensing and recording phenomena. Basic components comprising the instrument are: the BDX pressure sensor, the micro-honed recording disk, the drive motor, and the initiation system.

Basic construction consists of a circular top flange, which encompasses the pressure sensor. The interior gage components are housed in an aluminum frame, which is bolted to the flange. The drive motor and planetary gear train are set perpendicular to the axis of the turntable using a 4-to-1 bevel gear drive coupling. An antibacklash adjustment is accomplished by rotating the motor body within its mount. A 0.005-inch eccentric cut machined on the motor body permits the pinion gear to be moved against the ring gear located on the under side of the turntable, reducing backlash to a minimum. The turntable is a one-piece, cone-shaped unit, embodying the turntable face with ring gear at one end and a threaded stud at the small end for a lock nut retainer. The unit is suspended in two split-ring bearings, the primary bearing being located directly beneath the face. The turntable face is designed primarily for high pressure, using metal disks. The disks are $\frac{1}{32}$-inch stainless steel, with a microhoned finish, 3-inch outside, and a large $1\frac{7}{8}$-inch inside diameter.

The star-gear-cam limiting assembly was modified to allow a maximum of six revolutions with either a 10- or 20-rpm turntable speed. The assembly operates three microswitches. Two of these switches are used to control the motor and initiation circuits. The third switch limits the timing trace mechanism. A schematic of the gage circuit is shown in Figure A.23.

Timing marks are put on the record by means of a mechanical square-wave generator. The generator proper uses a pair of contrarotating masses and a coiled spring return which operates contact breaking and making the circuit to the energizing coil. The contacts are of a snap-action type and remain closed approximately 50 percent of the time. Connected in parallel to the energizing coil is a solenoid-operated scriber, which scribes a square wave on the recording disk. The generators have a nominal frequency of 50 cps, giving 20-msec timing marks. By their construction, they are relatively insensitive to acceleration in all modes. Tests indicate satisfactory performance during shock accelerations in excess of 80 g. This mechanism was developed under contract by the Exline Engineering Company, Tulsa, Oklahoma.

The power supply consists of two 14.4-volt Gulton rechargeable nickel cadmium batteries mounted in tubes drilled into the gage frame. The motor circuit utilizes one battery, while the initiation and square-wave generator circuits are paralleled on the second battery. The initiation and checkout circuits are basically the same as the PHS gage. The miniature hard-wire lead, however, enters the gage at the side of the flange, leaving the top surface clean. The flange with frame fastened in place is bolted into an aluminum case with an O-ring seal. One-half of a $1\frac{1}{2}$-inch pipe coupling is welded to the base of the case to facilitate field mounting.

A.4.5 PGS-1S Gage. The PGS-1S gage is essentially a PGS gage which has been shock-mounted. Beyond a diameter change on the circular flange and several tapped holes, the PGS gage is unchanged. The method of shock-mounting is shown in schematic form in Figure A.24. Basically, the gage is suspended at a band around the frame and an area around the pressure inlet port, in a shock-resistant compound developed by Barry Controls, Inc. Presented in Figure A.25 are photographs which further illustrate the PGS-1S gage.

A.4.6 PNS Gage. The PNS gage shown in Figures A.26 through A.28 features a radical departure from the conventional motor drive of the standard gage. The gage motor is a standard stainless steel negator spring, using its self-winding feature to supply a constant torque. Upon initiation, the spring unwinds from an output drum, around an idler or recording drum, and onto its storage drum, where the spring comes to rest on a nylon bobbin. One end of the spring is cut and shaped to secure it to the output drum. The remainder of the spring is microhoned on one side to a smooth finish, similar to the conventional metal disk used on the PGS and PHS gages. This microhoned surface is utilized as the PNS gage-recording medium, when the spring passes over the recording drum. The only device driven by the spring torque is a governor geared to the output drum, which maintains a spring travel of approximately 3 in/sec. An additional spring device is temporarily geared to the output drum and governor, which gives a starting kick upon initiation. Startup times approximate 25 msec.

Basic construction consists of a circular top flange, which encompasses the pressure sensor. The motor, governor, and initiation components are attached to the top plate as one assembly. The square-wave generator scribe, identical to that on the PGS gage, is attached to the top flange as a second assembly. An eccentric feature on the recording drum moves the spring recording surface to, or away from, the stylus complex. This complex includes the pressure sensor, the time-generator scribe, and a third stylus which serves as a fixed reference line. The 20-volt mercury cell power supply and the Exline square-wave generator are located in the base of the gage case.

Arming the gage is accomplished by turning a small shaft 90 degrees. One end of this shaft is located flush with the outside surface of the flange and is slotted for screwdriver use. This action accomplishes two functions. It arms the initiation circuit and activates the eccentric feature described in the above paragraph. The checkout circuit serves the same purpose as that on the PHS gage; however, there is no external reset arrangement on the PNS gage. A schematic of the gage circuit is shown in Figure A.29.

A.4.7 QGS Gage. The QGS or dynamic pressure gage shown in Figures A.30 and A.31 is a modification of the standard Q gage which has been used on every operation since Castle. The primary change is in the motor-turntable assembly, which is basically a redesign of the PGS gage frame. The Globe motor and gear drive are identical, while the turntable surface is machined smaller to fit within the Q gage nose. It requires a smaller disk, $2\frac{1}{4}$-inches outside and $1\frac{1}{8}$-inches inside diameter. All initiation and limiting units are part of the power pack, located in the gage stinger. The nose shell is modified to permit the use of a single diaphragm (USG-D) sensor at the total pressure inlet. An extension was added to the rear for an O-ring seal for better support. The forward end of the nose is made in three shapes: round, a 30-degree included angle, and a 60-degree included angle. All are made of steel.

The gage stinger shown in Figure A.31 is similar to those used on Plumbbob in the high-pressure region, but includes several extra strength design features. Fins were welded at the rear, more material was used in the wall, and six set screws were used to add strength to the coupling area around the nose junction.

The power pack was a modification of those used in the standard Q gage on Plumbbob. The motor power supply consists of five 4.05-volt mercury cells in series, which is in parallel with two motors. One is the turntable drive Globe motor and the second is a PHS type Hayden motor which drives a limiting mechanism similar to the star-gear-cam assembly on the PHS gage. The initiation circuit and arming switch assembly are identical to those used on the PHS gage. The power pack unit is secured to a circular plate, which mounts into the Q stinger from the rear with an O-ring seal. The arming screw and hard-wire lead are located in the power pack plate. Shown in Figure A.32 is a schematic of the circuit.

A.4.8 VLP Gage. The VLP gage is shown in Figure A.33. It consists of a single 5-inch-diameter corrugated diaphragm mounted in a rectangular case. A single-hole orifice plate and wind filter are located in front of the diaphragm; a multihole damping plate is located between the diaphragm and case. Batteries for powering a 3-rpm Hayden drive motor and turntable are located inside the gage case. A bleed plug is located on one side of the gage case to allow a gradual equilibrium of internal and ambient pressures.

TABLE A.1 TRANSDUCER CHARACTERISTICS

Solid-State Bonded Strain	Wire Bonded Strain	Wire Unbonded Strain	Variable Reluctance
	ADVANTAGES		
Good linearity hysteresis and repeatability	Excellent linearity hysteresis and repeatability	Good linearity hysteresis and repeatability	Fair linearity hysteresis and repeatability
Low sensitivity to shock and vibration	Low sensitivity to shock and vibration	May be ac or dc excited	Very rugged
May be ac or dc excited	May be ac or dc excited	Continuous resolution	High sensitivity
Continuous resolution	Continuous resolution	Low thermal zero shift	Continuous resolution
High frequency response	High frequency response	Availability of low-pressure ranges	
High sensitivity	Low zero thermal shift		
	Rugged because strain gages are not coupled to diaphragm.		
	DISADVANTAGES		
Low-pressure range limitations	Low-pressure range limitations	Delicate	ac excitation is necessary
Thermal zero shift	Low sensitivity	Low sensitivity	Must be reactively and resistively balanced
Delicate strain elements			Low frequency response
Limited temperature range			Proximity to magnetic fields or objects causes erratic performance.

TABLE A.2 PRESSURE SENSOR CHARACTERISTICS

Item	USG Capsule	USG Diaphragm	BDX Diaphragm
Diaphragm material, high range	Ni Span c	Ni Span c	Ni Span c
Diaphragm material, low range	Beryllium copper, 1 psi Phosphor bronze, 0.5 psi	Beryllium copper, 1 psi only	Beryllium copper, 0.5 psi only
Deflection at rated pressure	0.035 to 0.050 inch	0.015 to 0.030 inch	0.015 to 0.030 inch
Rise time, high range	1 to 3 msec, 5 psi and above	0.2 to 1 msec approximately, when critically damped	0.2 to 0.5 msec approximately, when critically damped
Rise time, low range	3 to 5 msec, 1 psi and less	Same as above	Same as above
Damping	Orifice with 80-mesh monel metal screen	Orifice	Orifice
Linearity	±0.5 to 5.5 percent, 0.5 to 400 psi ±10 percent, 800 to 1,000 psi	±0.5 to 5.5 percent, 1 to 400 psi ±10 percent, 800 to 1,500 psi	5-percent ranges, 2 to 1,000 psi 15-percent ranges, 2,000 to 3,000 psi
Hysteresis	±0.1 percent, 0.5 to 400 psi ±5 percent, 800 to 1,000 psi	±0.1 percent, 0.5 to 400 psi ±5 percent, 800 to 1,500 psi	2 percent, all ranges
Operating range	Will withstand 100 percent Will withstand 25 percent	Overpressure, 0.5 to 400 psi Overpressure, 800 psi and above	
Diameter	0.75 to 2.00 inches	0.75 to 2.00 inches	1.25 inches for all ranges
Stylus motion restrained	No	No	Yes
Ranges available	0.5 to 1,000 psi	1 to 1,500 psi	0.5 to 3,000 psi

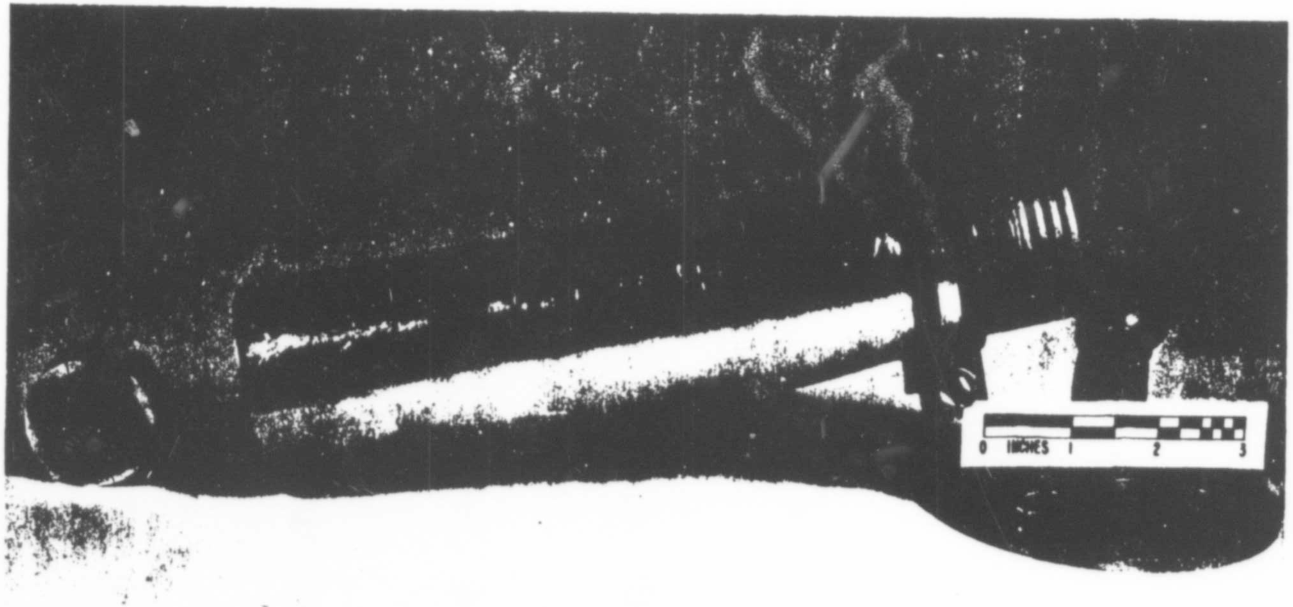


Figure A.1 Solar cell with mount. (BRL photo)

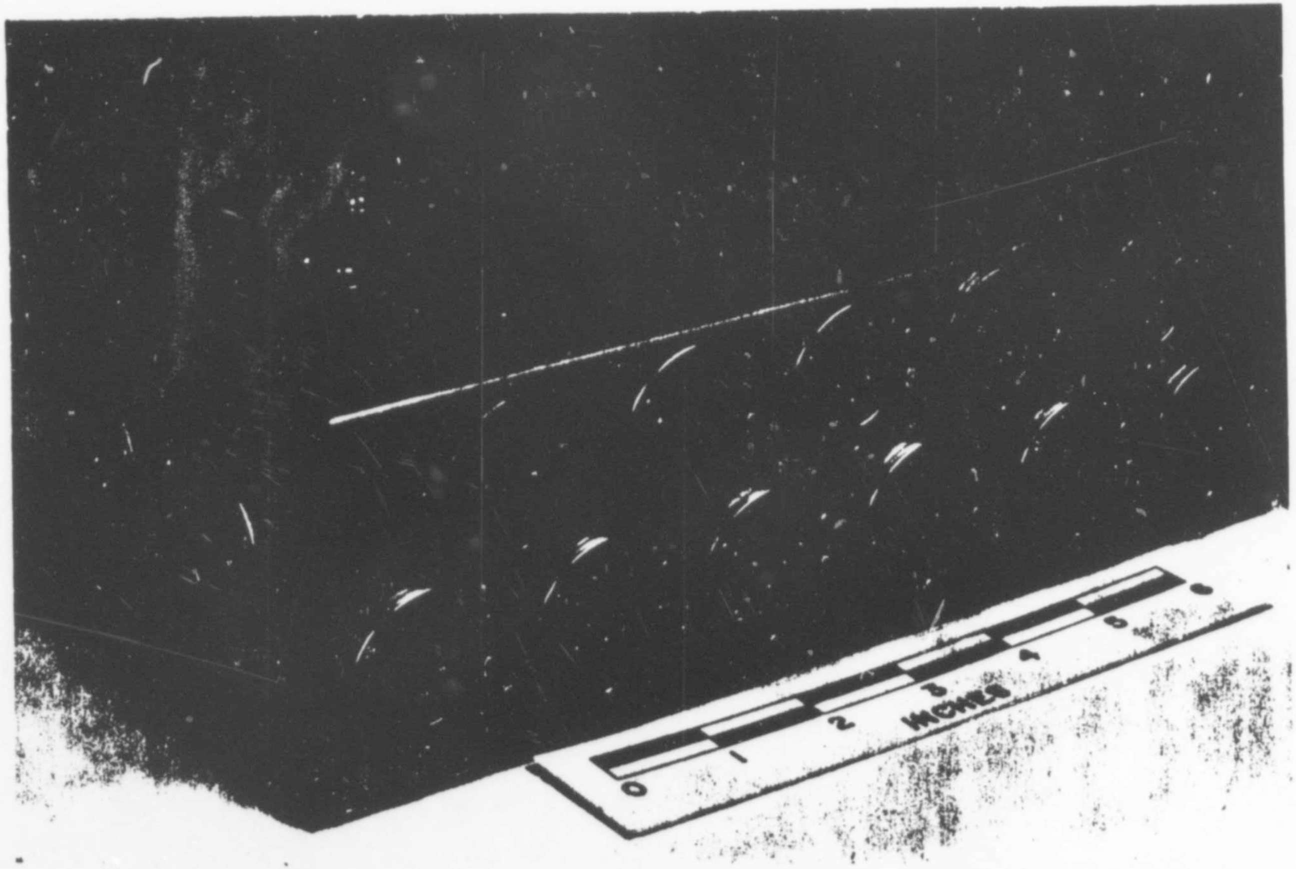


Figure A.2 Time zero distribution box. (BRL photo)

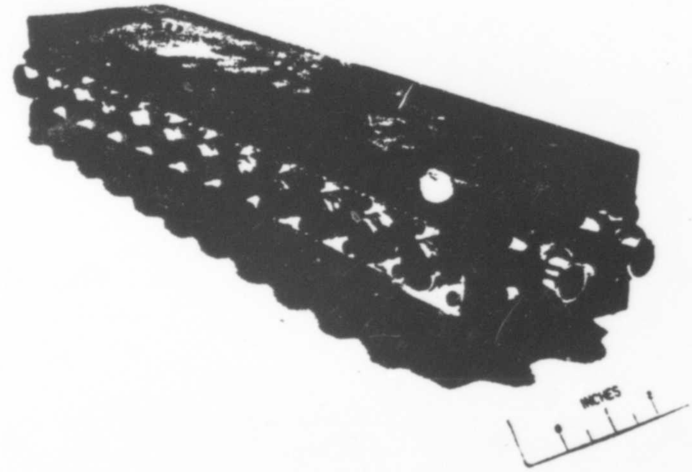


Figure A.3 Transducer signal line grounding relay box. (BRL photo)

Figure A.4 Dynisco pressure transducer (PT 76). (BRL photo)

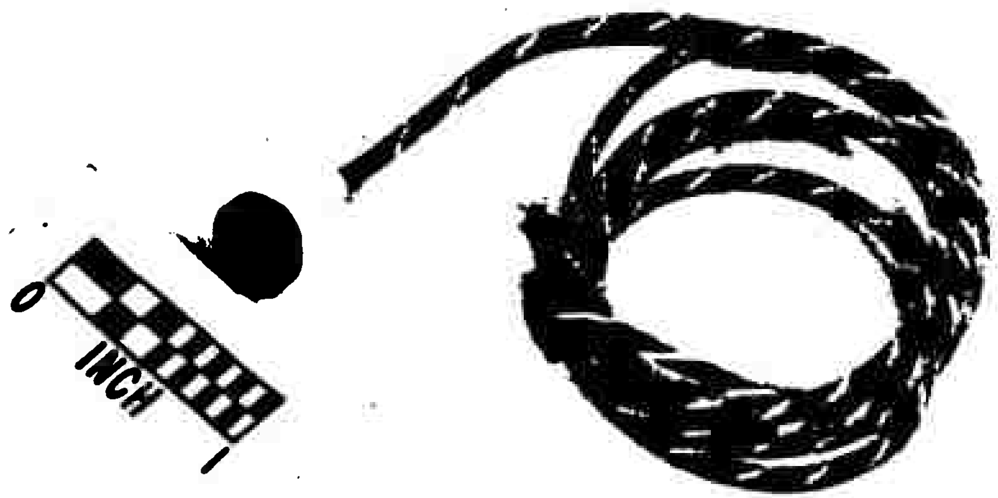


Figure A.5 Micro Systems pressure transducer (P03). (BRL photo)

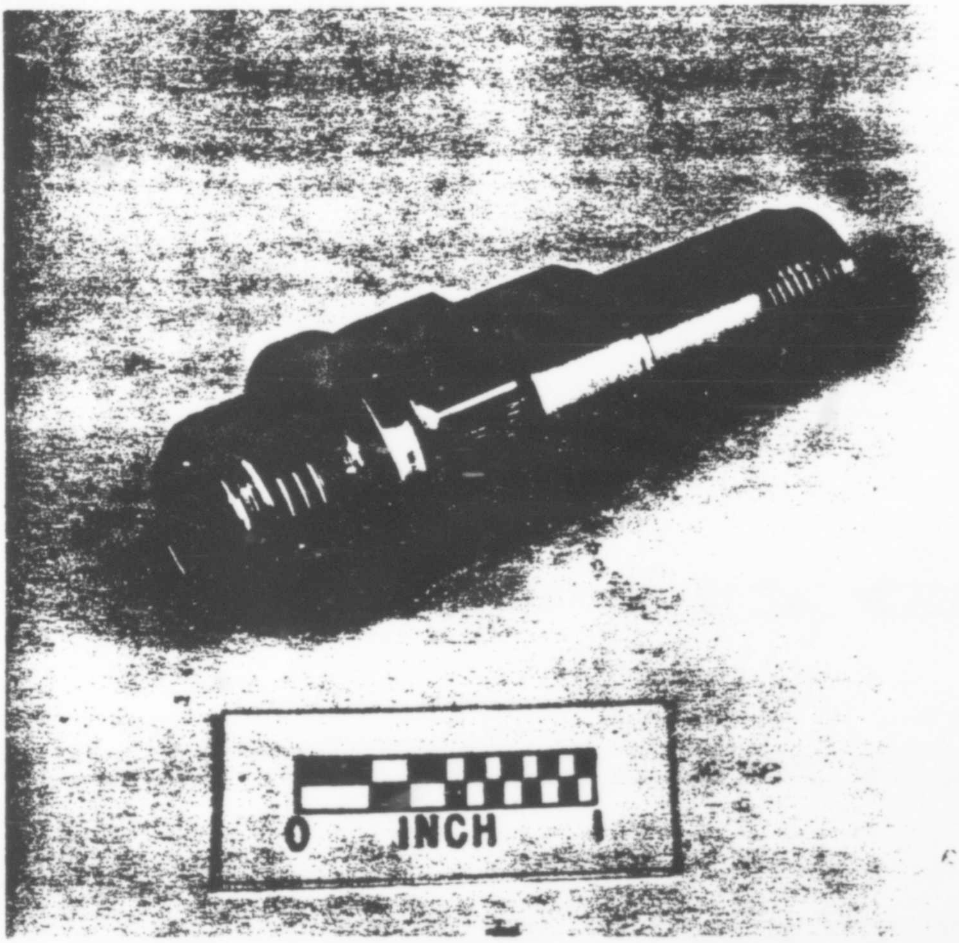


Figure A.6 Norwood Controls pressure transducer (111). (BRL photo)

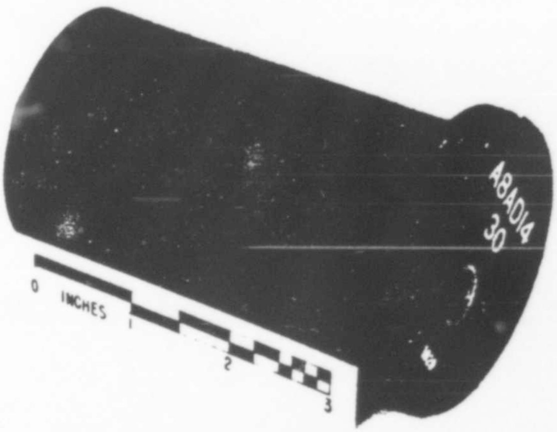


Figure A.7 Wiancko pressure transducer (P1405). (BRL photo)

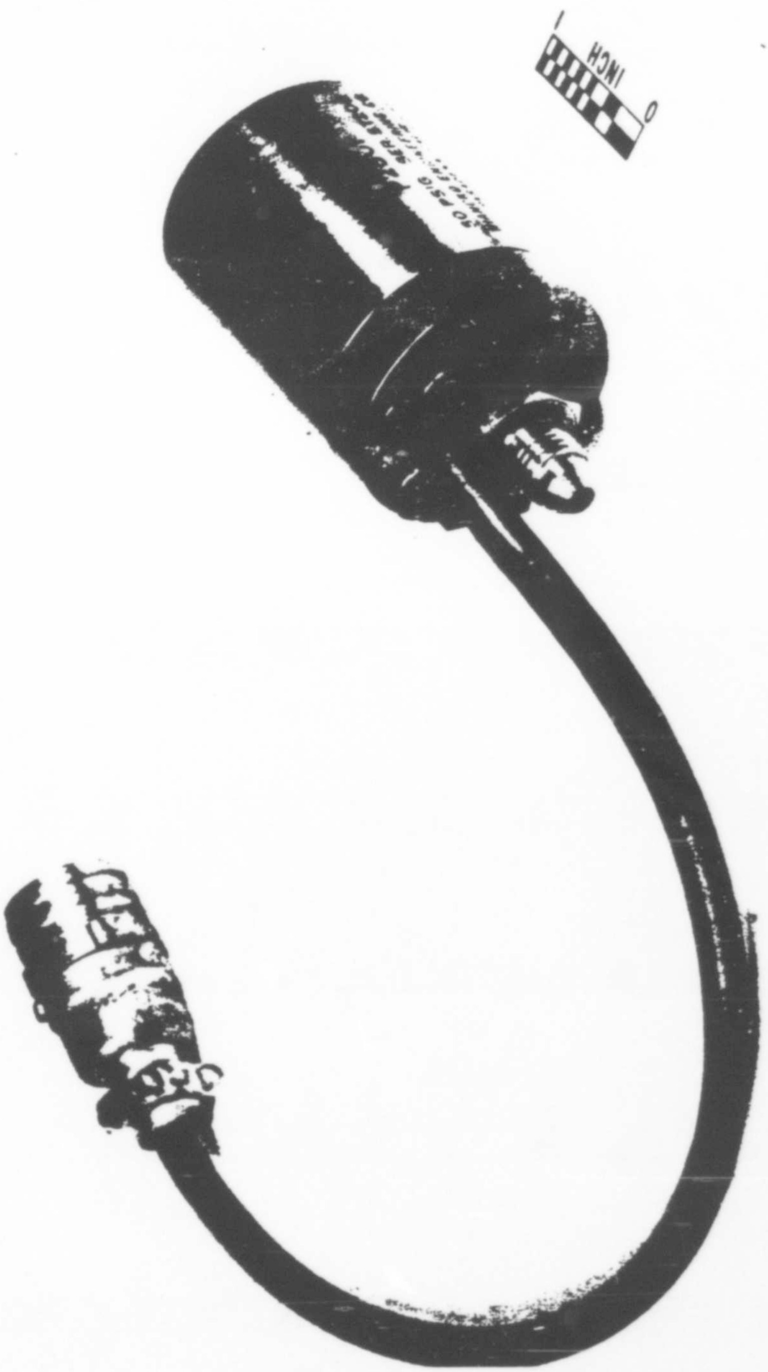


Figure A.8 Wiancko pressure transducer (P2801). (BRL photo)

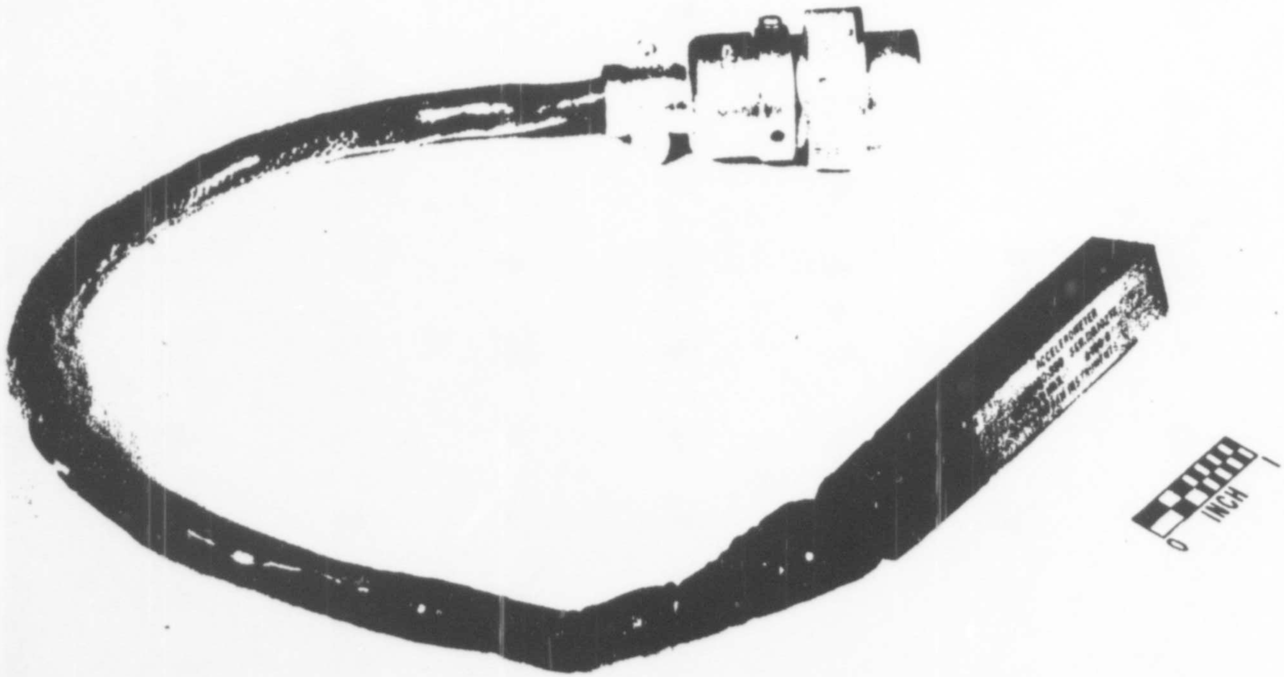


Figure A.9 Statham accelerometer (A9). (BRL photo)

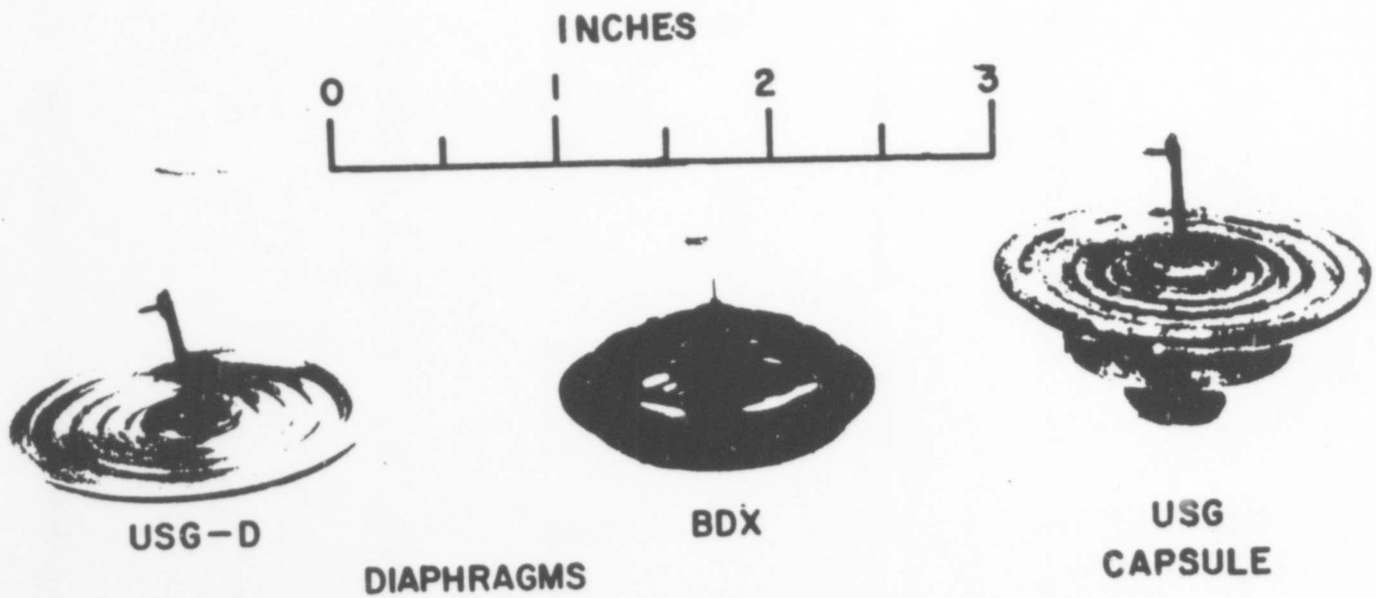


Figure A.10 Pressure sensors, self-recording gage. (BRL photo)

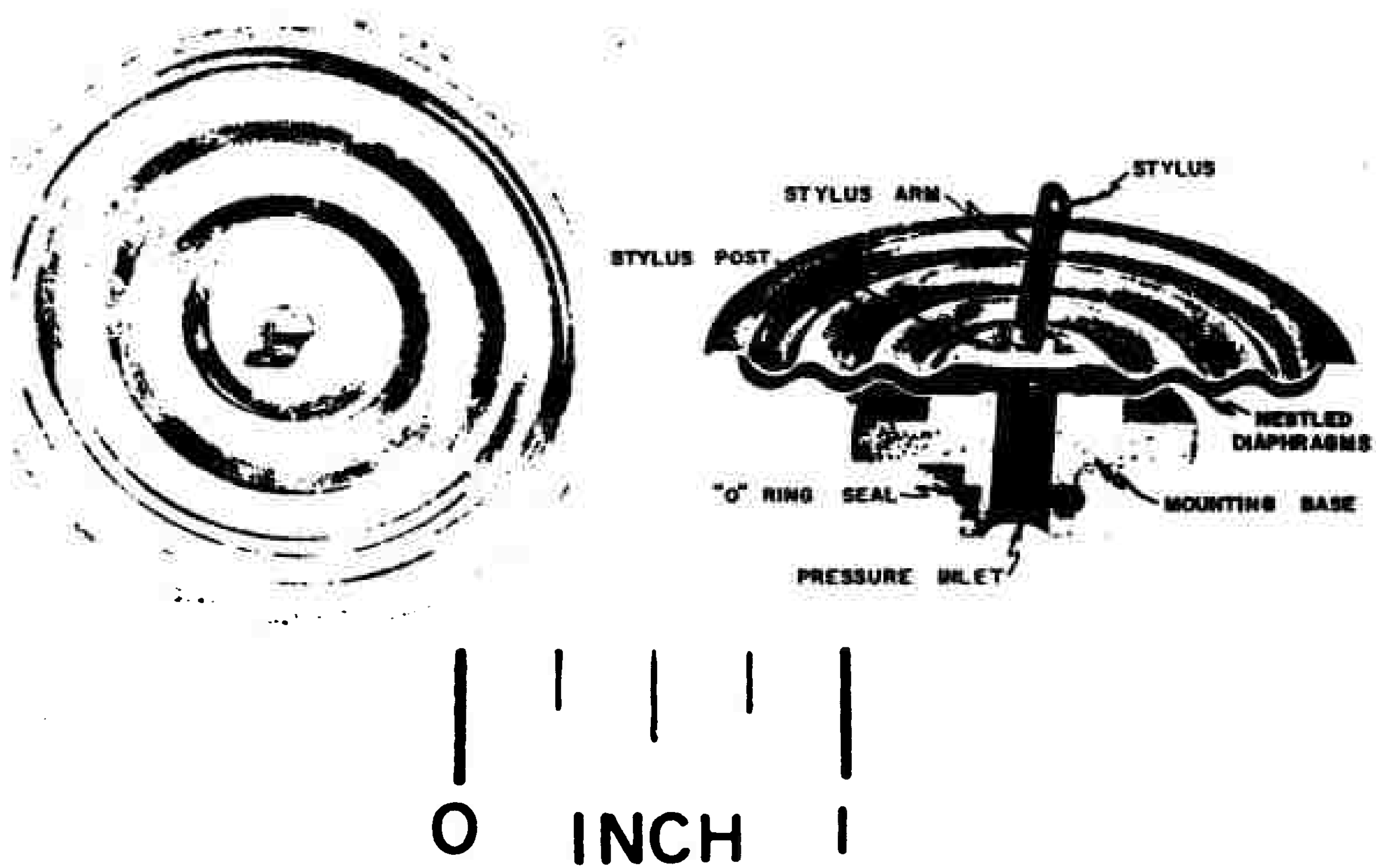


Figure A.11a Cutaway view of USG capsule. (BRL photo)

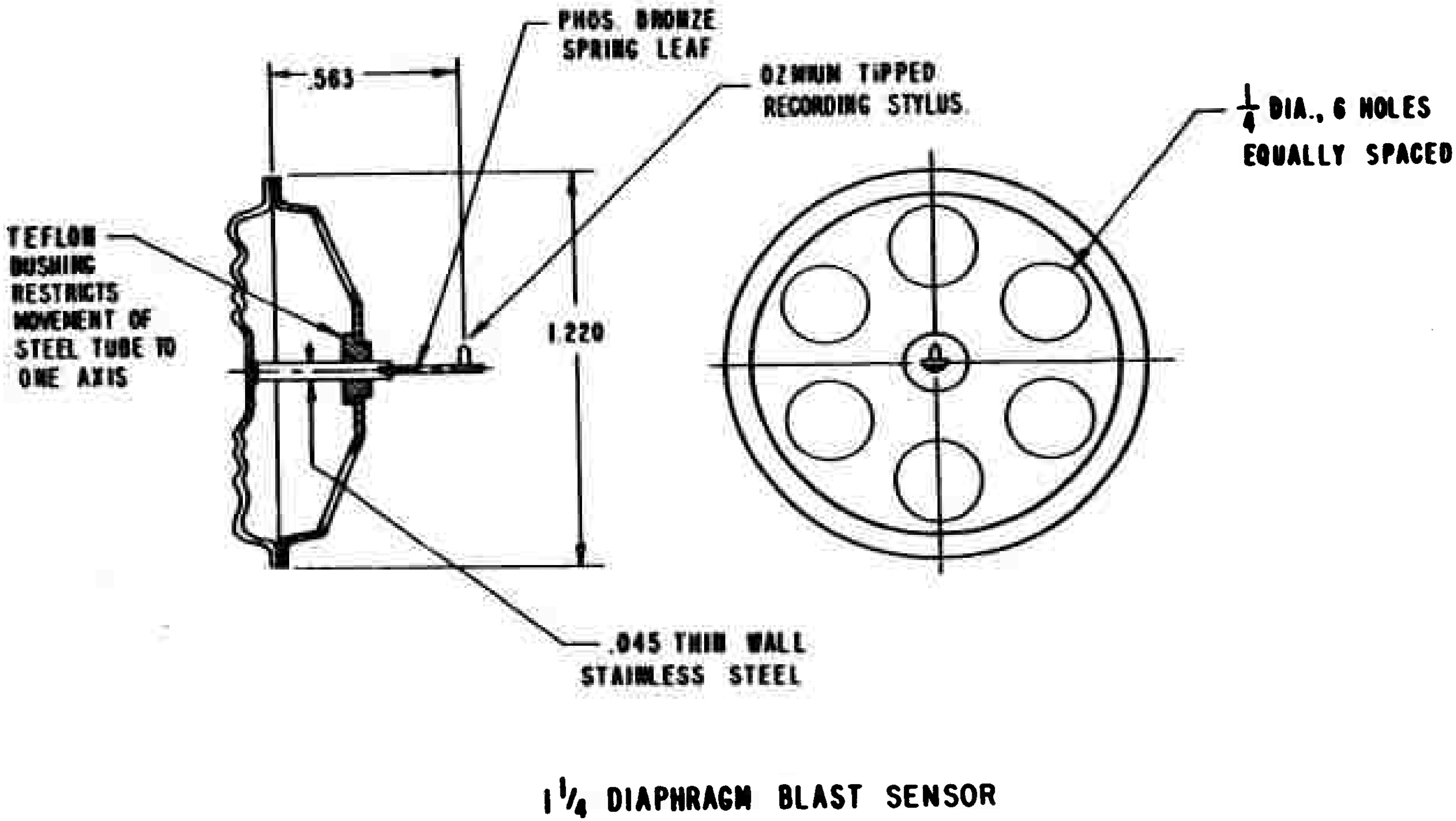


Figure A.11b Schematic of BDX sensor.

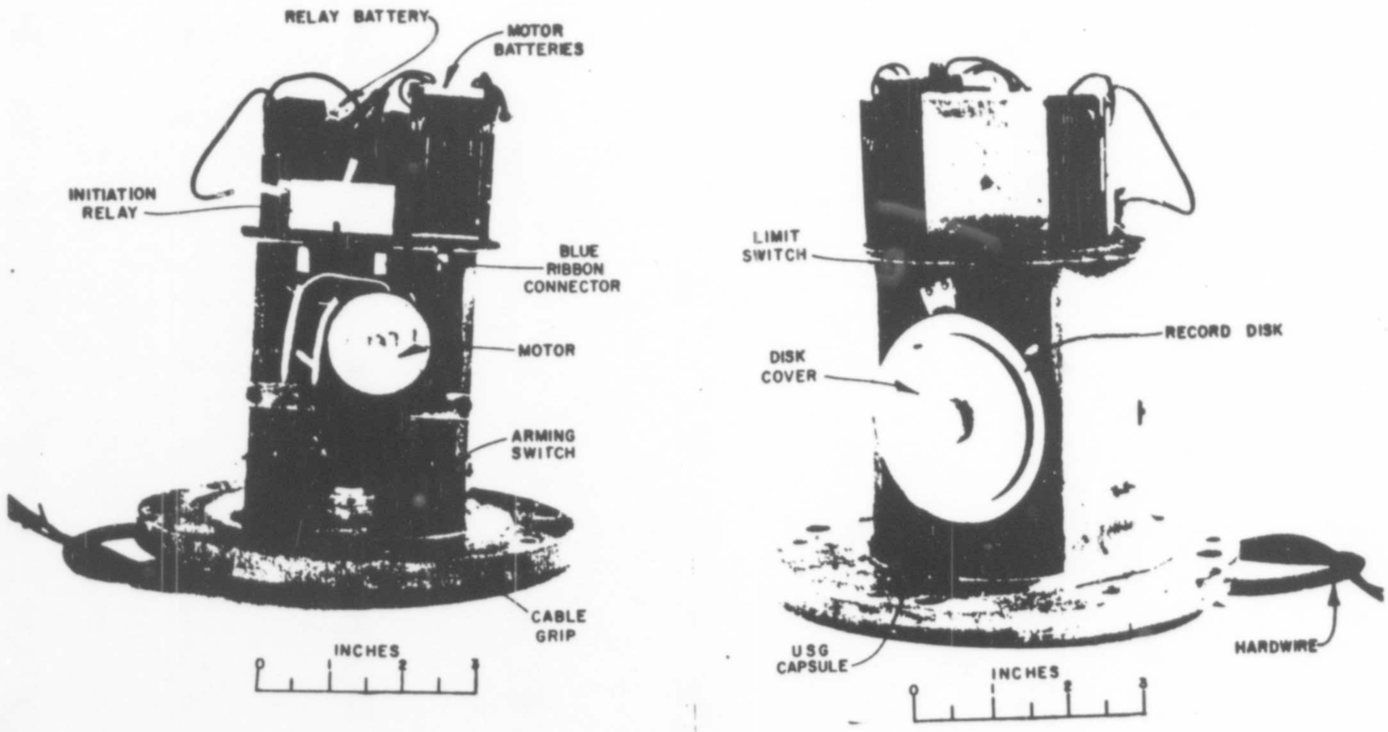


Figure A.12 Detailed view of PHS gage. (BRL photo)

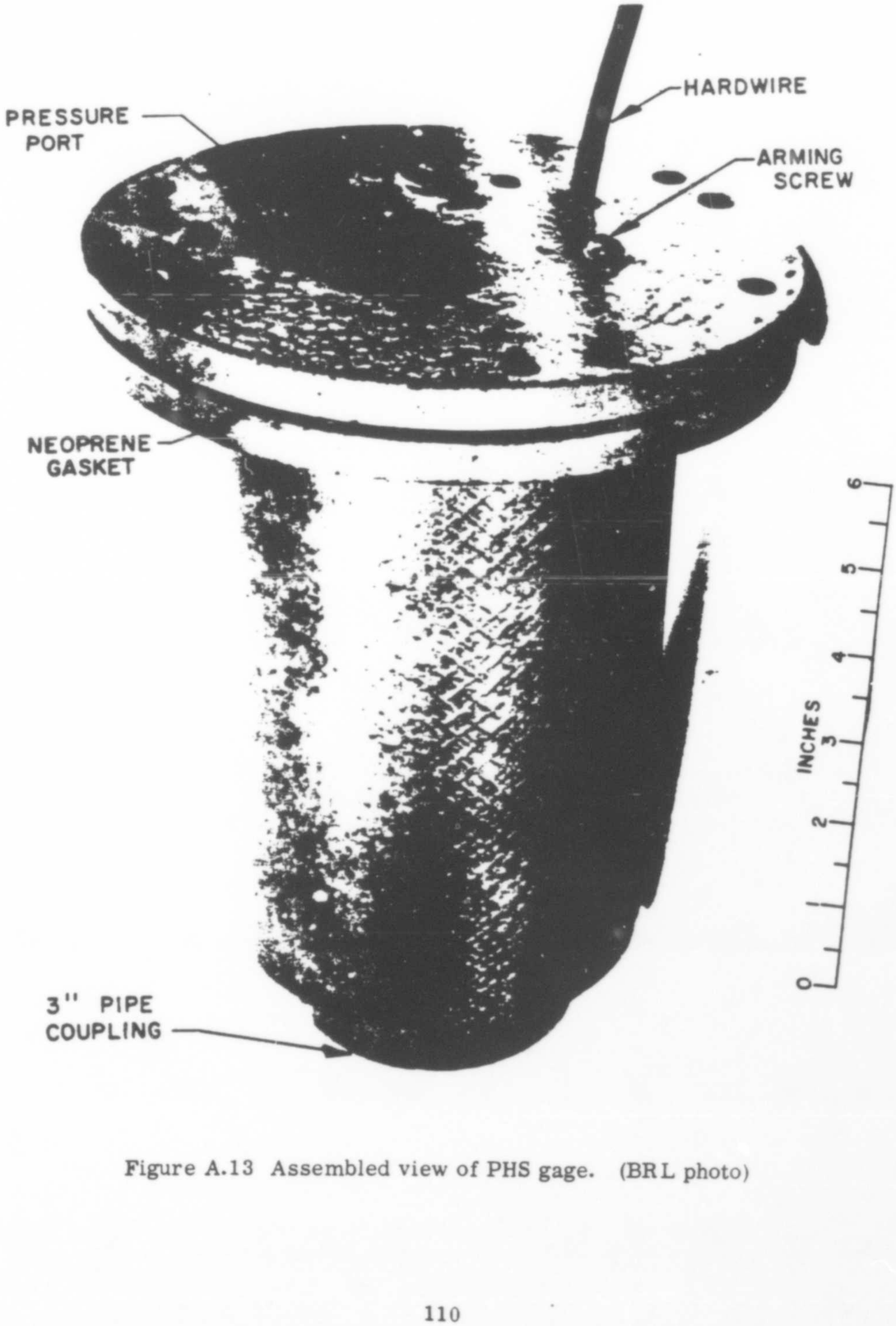


Figure A.13 Assembled view of PHS gage. (BRL photo)

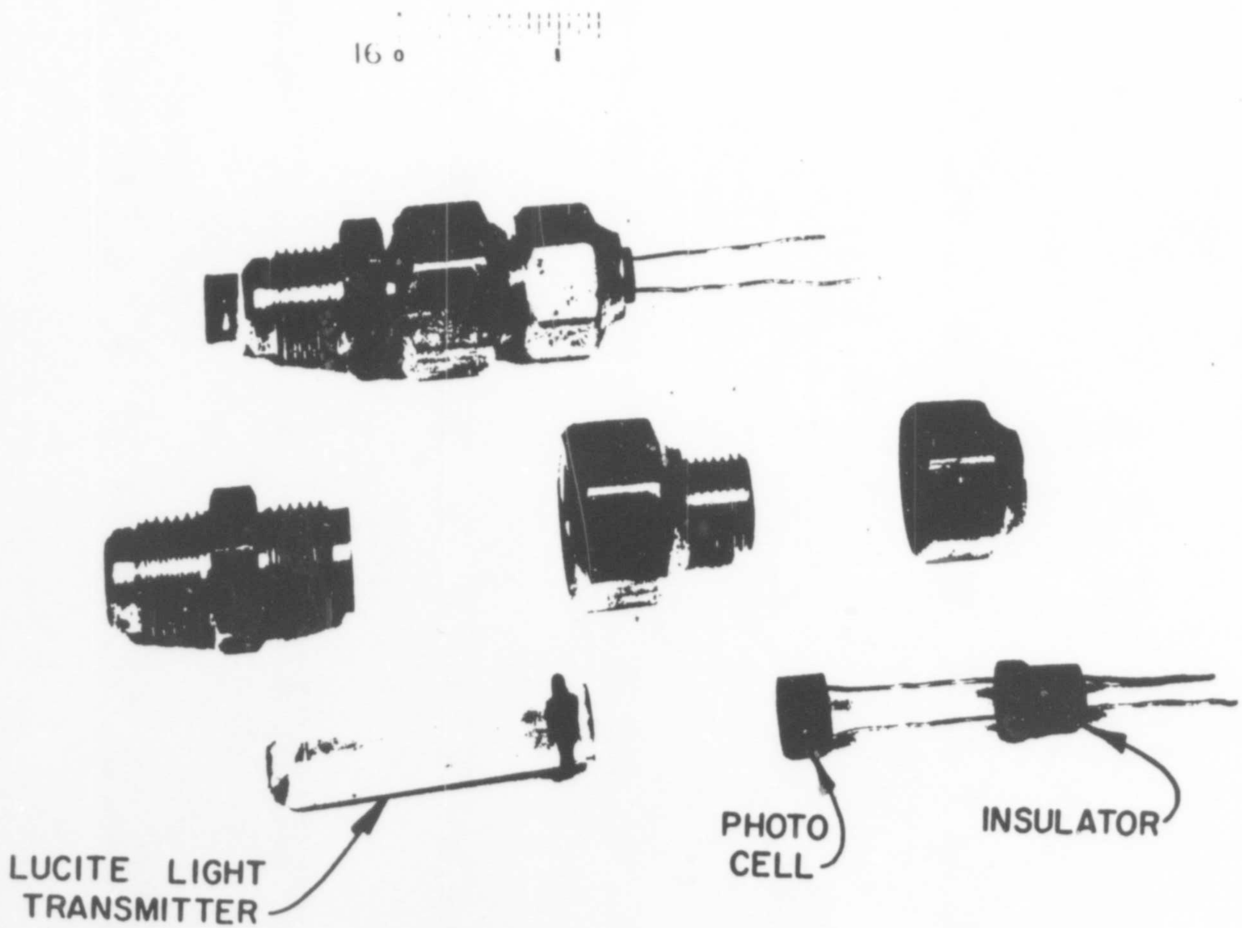


Figure A.14 Exploded view of photocell assembly. (BRL photo)

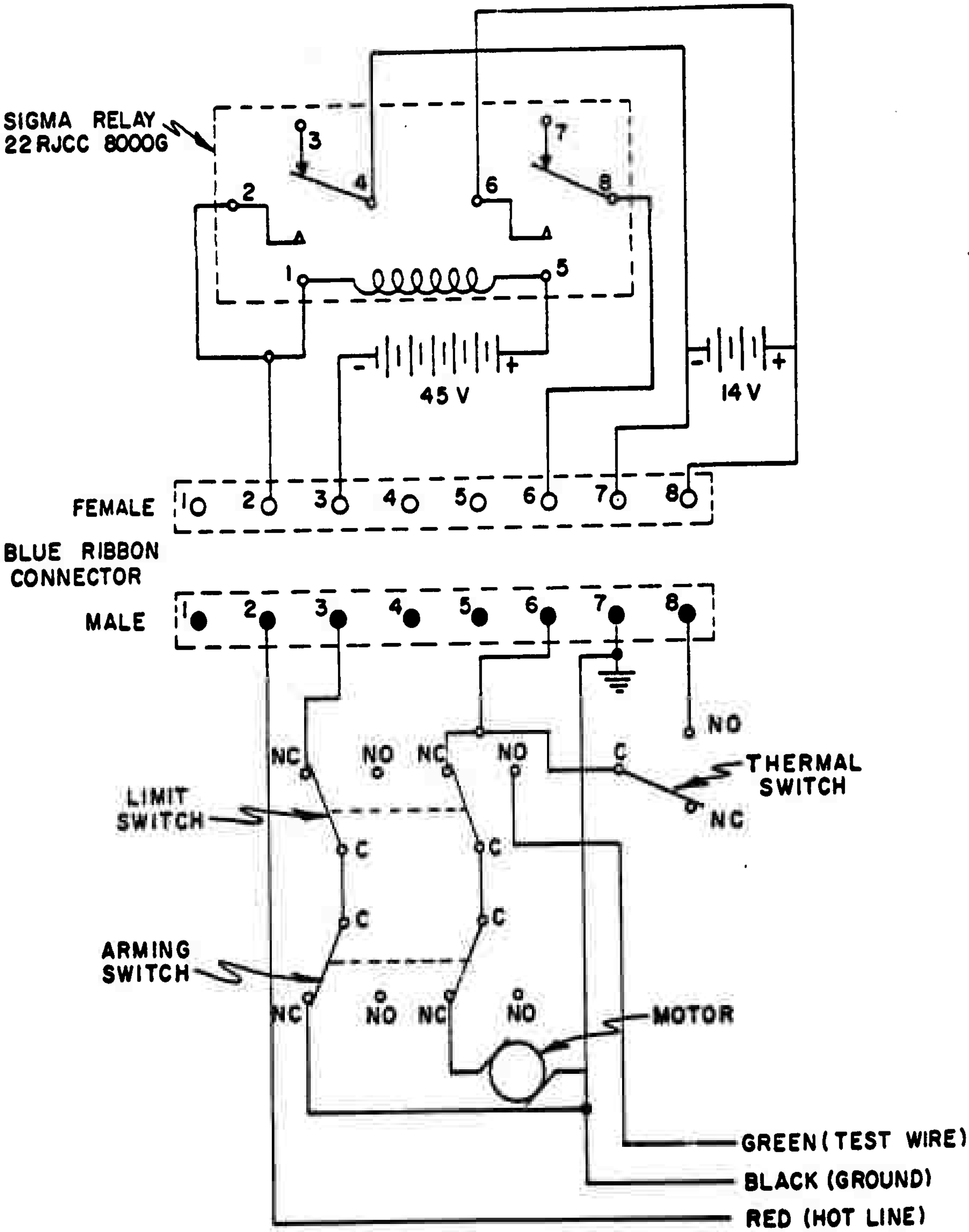


Figure A.15 Schematic of PHS gage circuit.

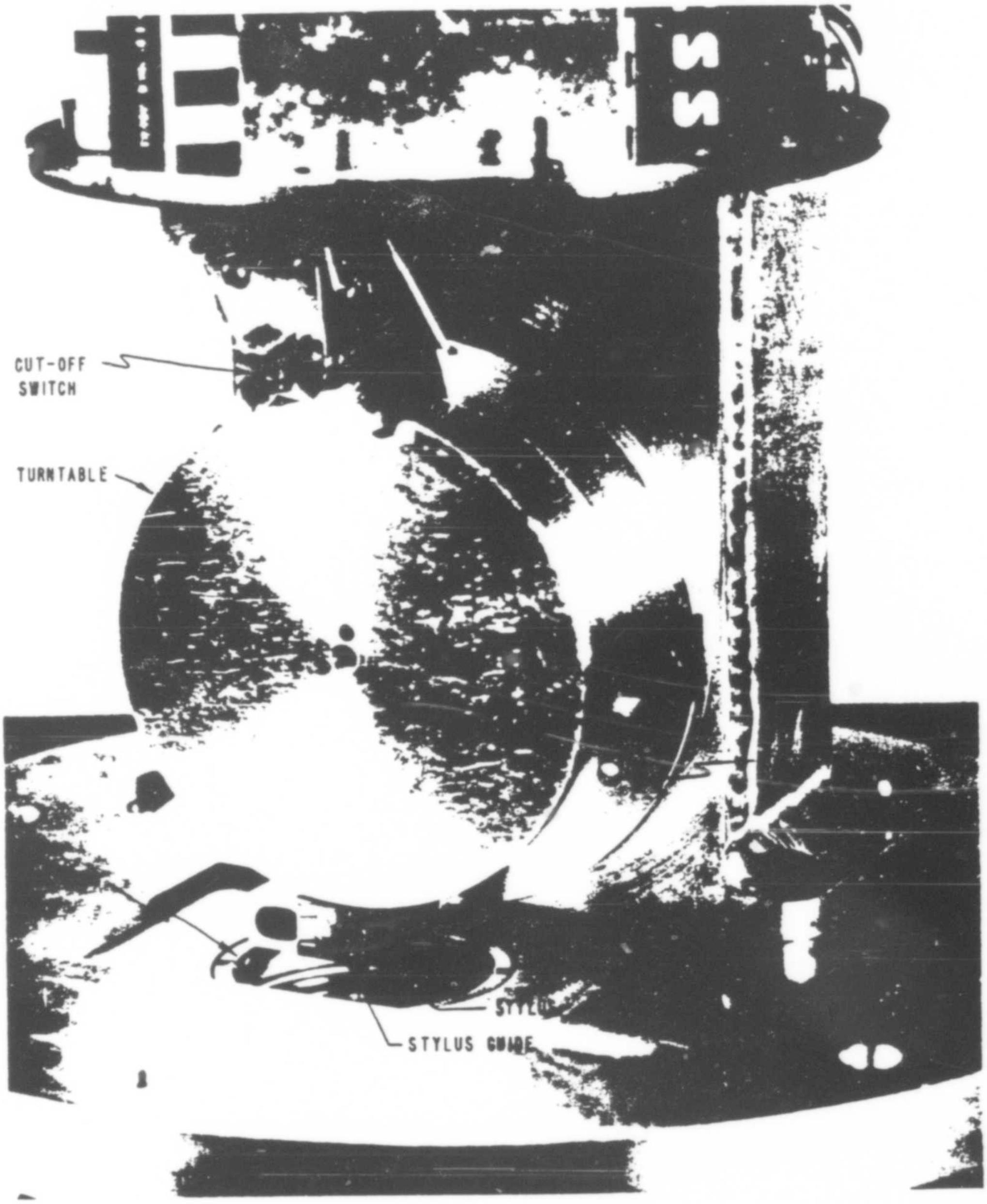


Figure A.16 View of USG diaphragm in PHS gage. (BRL photo)

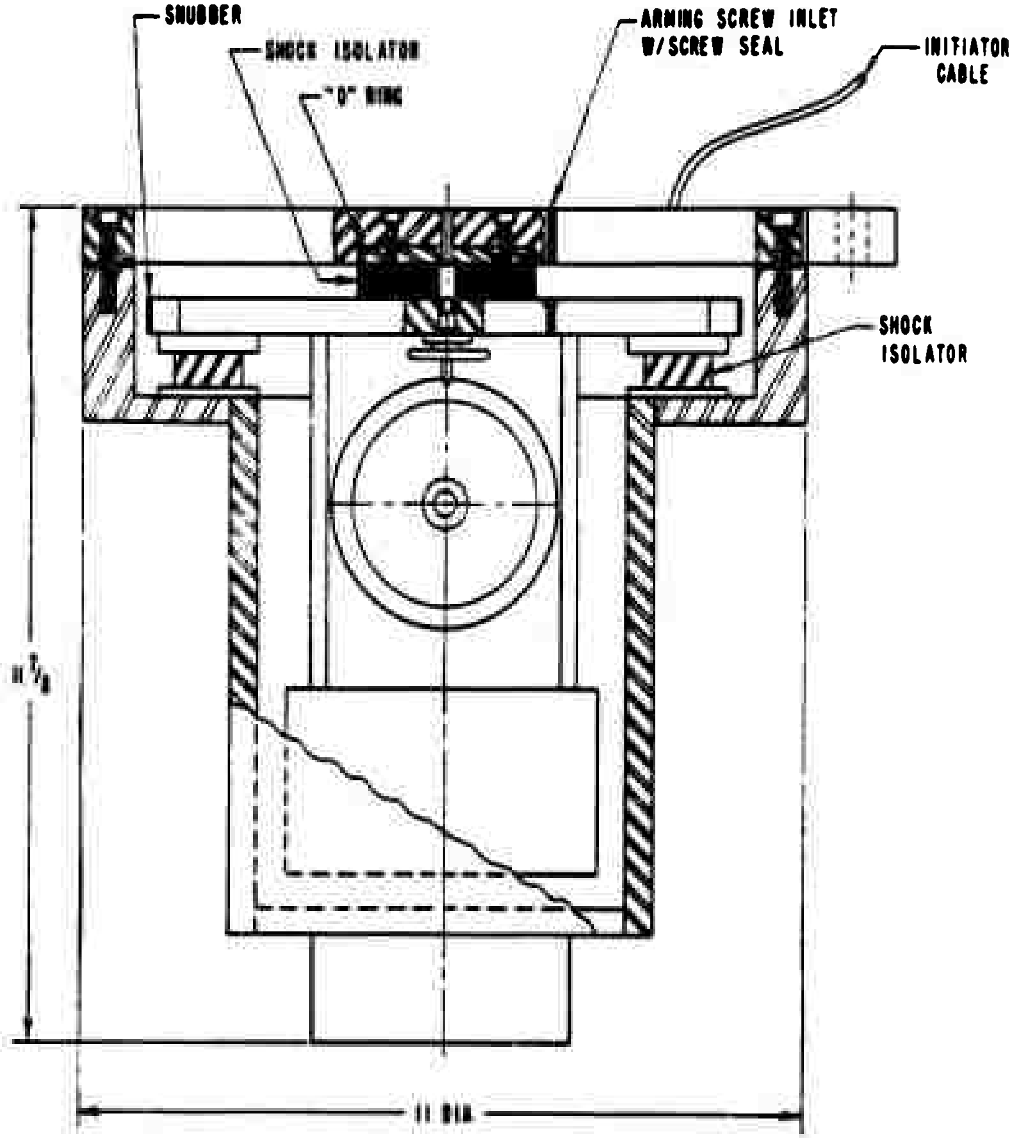


Figure A.17 Schematic of PHS-1S gage.

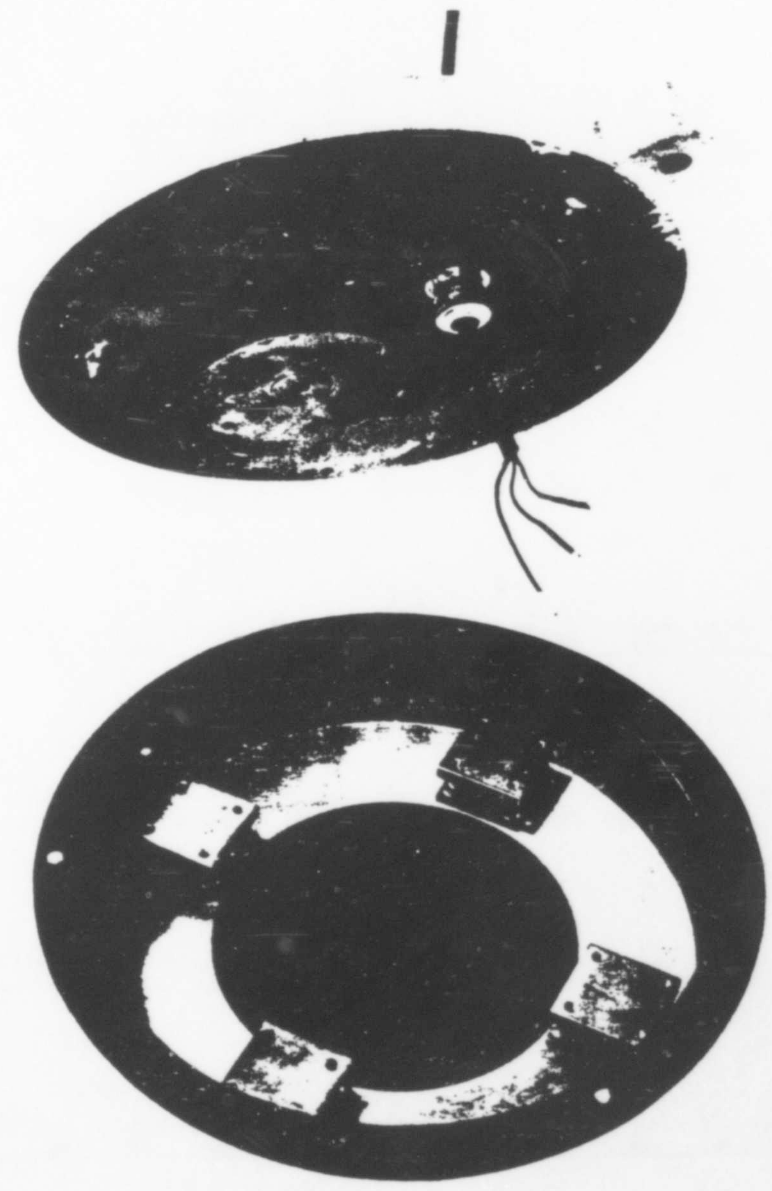
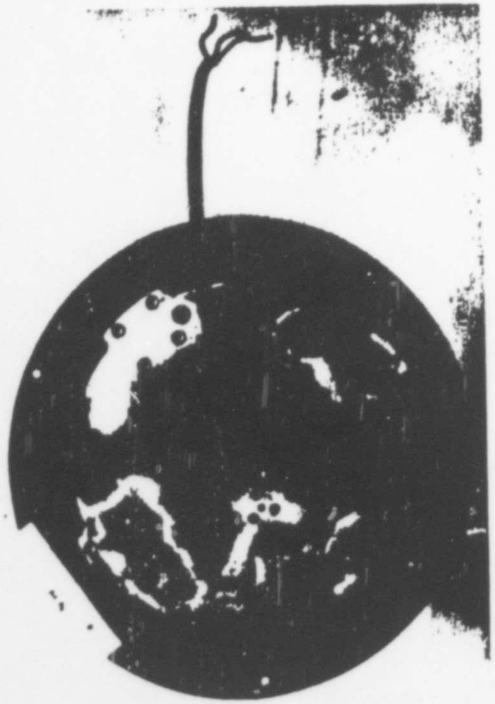
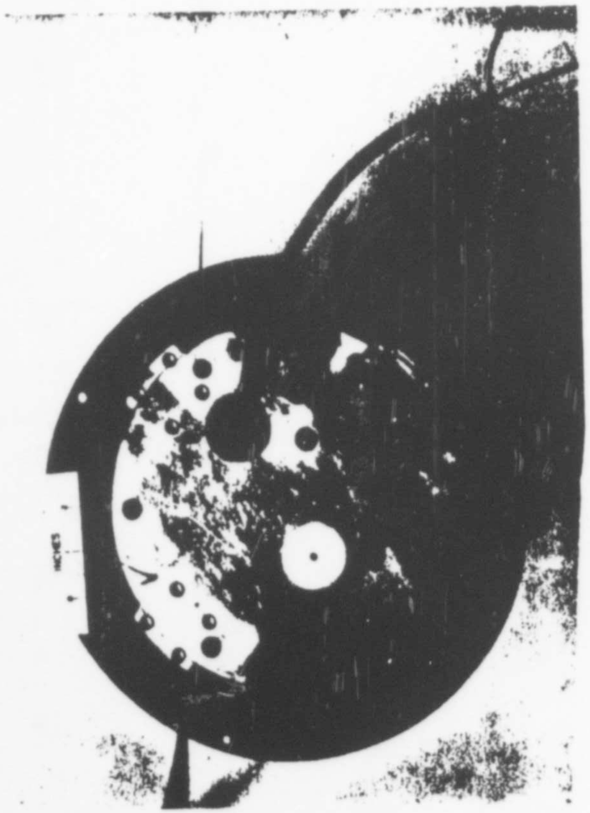


Figure A.18 View of PHS-1S shock isolation system. (DASA 524-19-NTS-62)



Capsule gage



Diaphragm gage

Figure A.19 View of capsule gage and diaphragm gage mounted on shock isolators. (BRL photo)

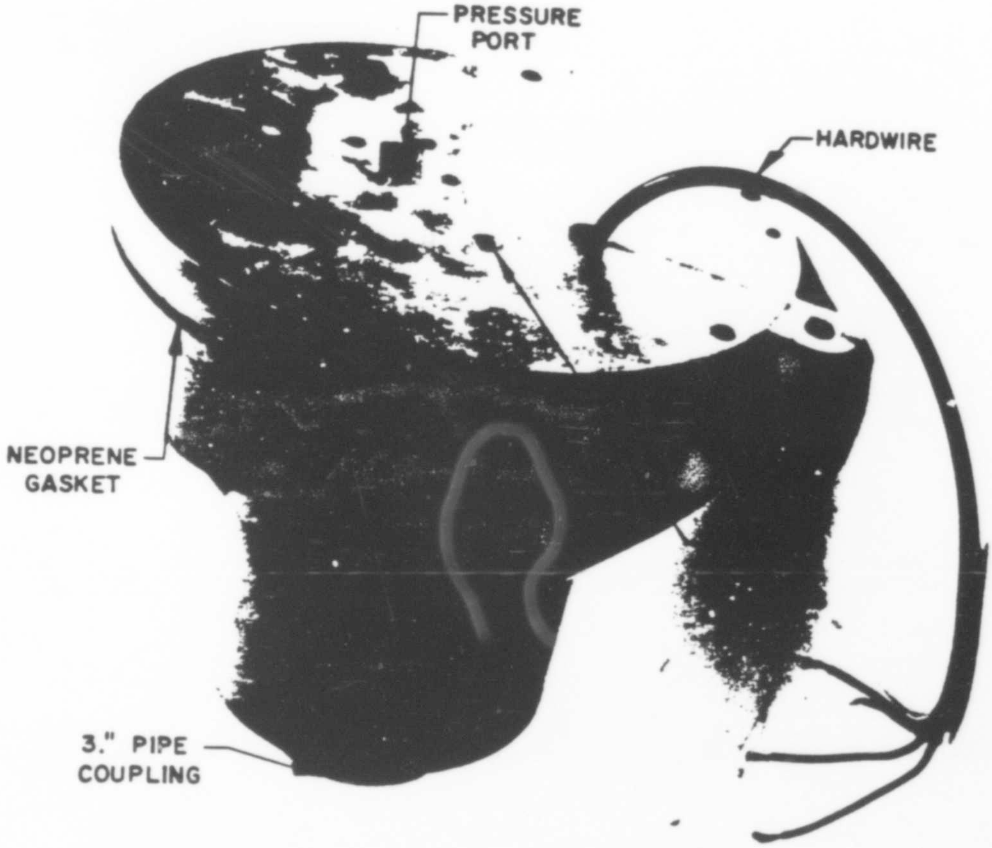


Figure A.20 Assembled PHS-1S gage. (BRL photo)

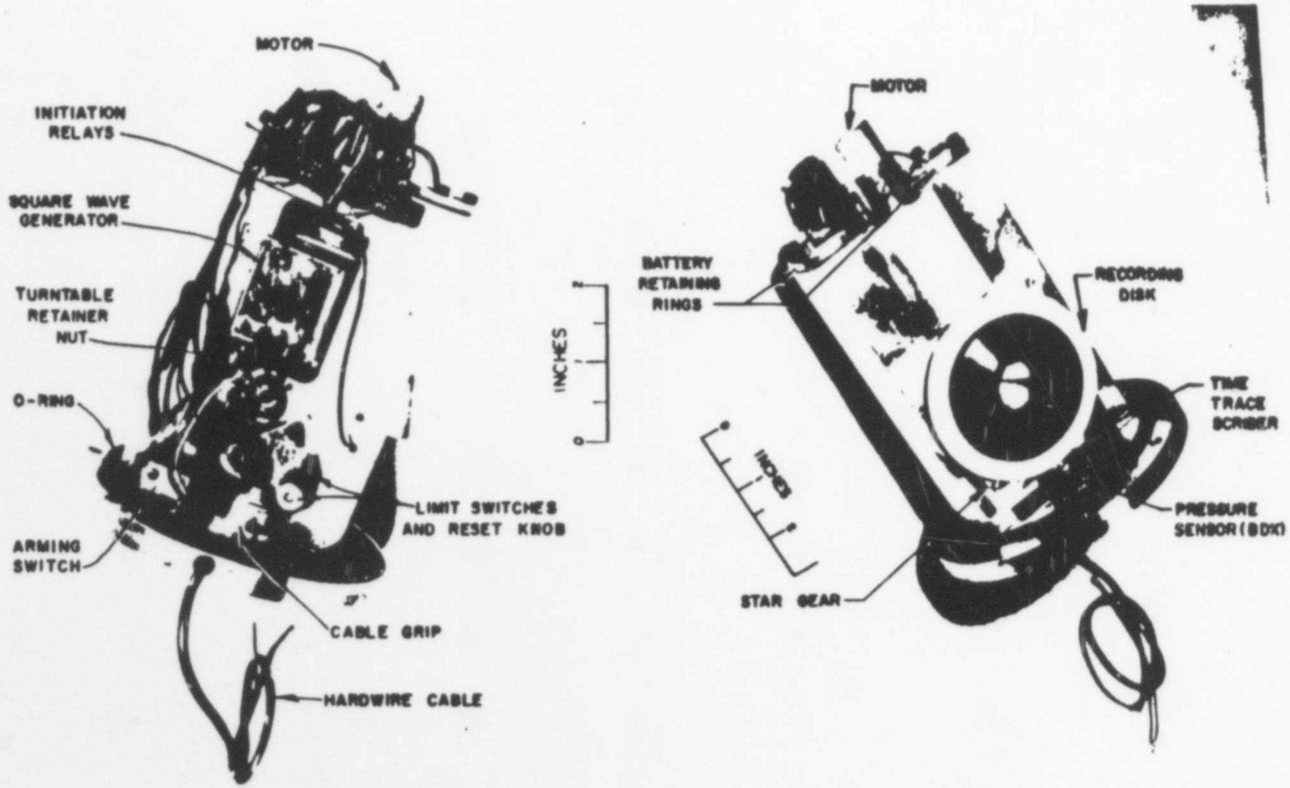


Figure A.21 Detailed view of PGS gage. (BRL photo)

Figure A.22 Assembled view of PGS gage. (BRL photo)

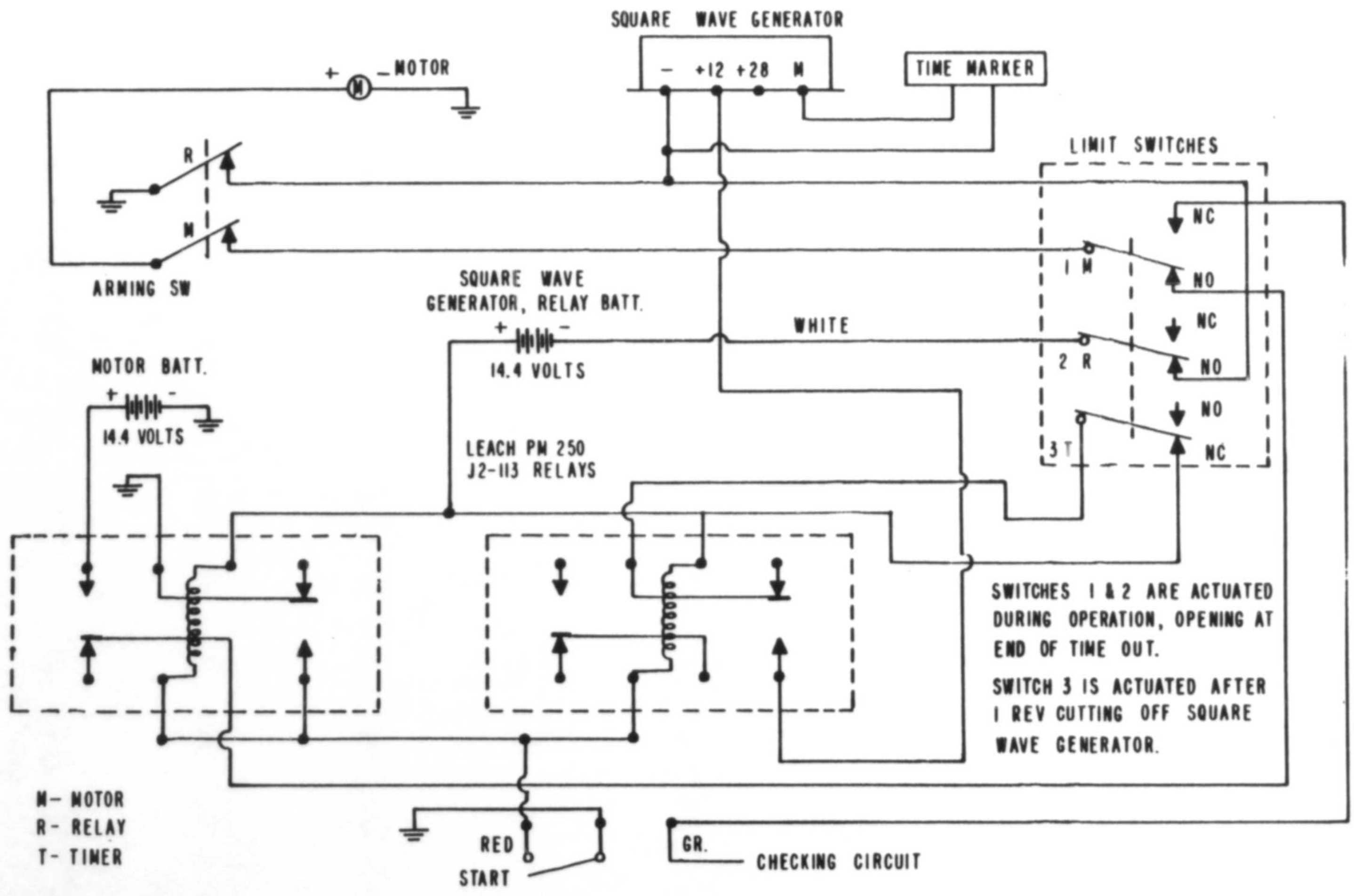


Figure A.23 Schematic of PGS gage circuit.

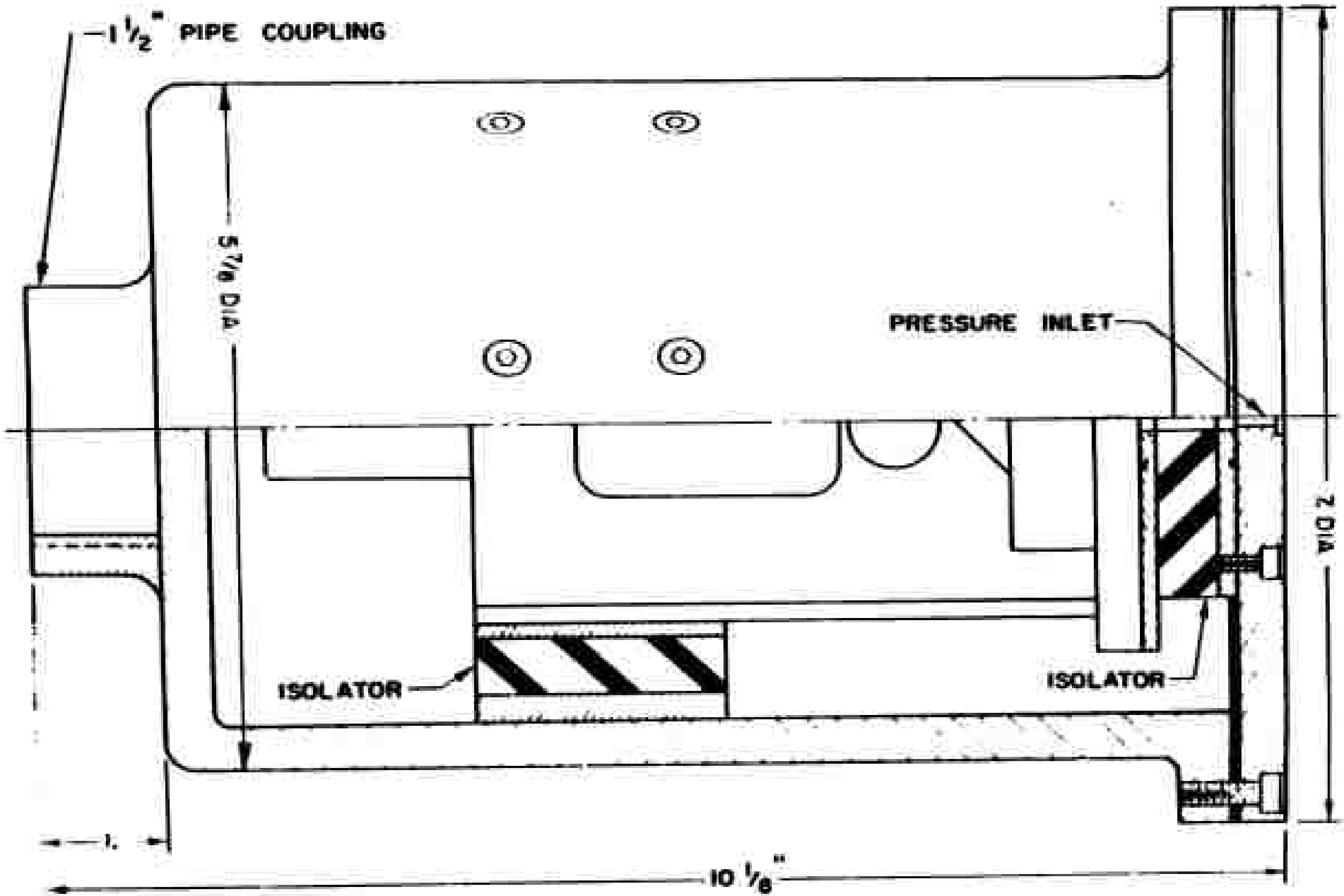


Figure A.24 Schematic of PGS-1S gage.

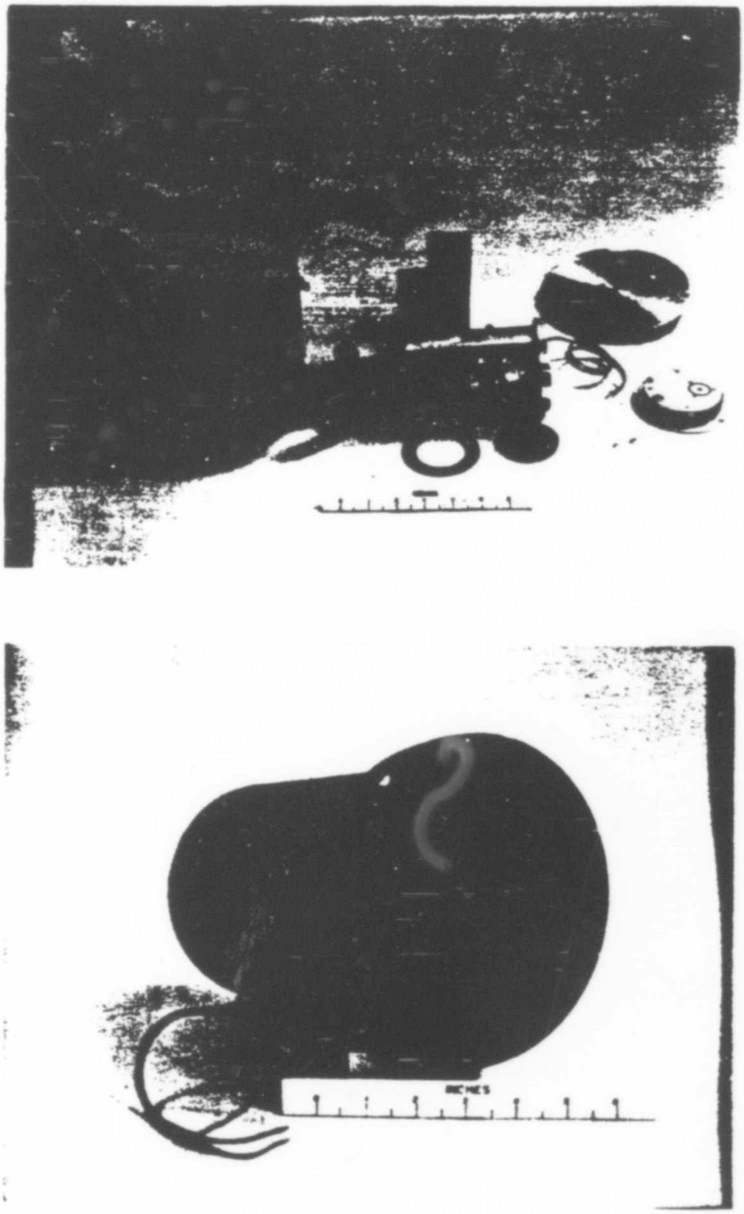


Figure A.25 Exploded view and assembled view of PGS-1S gage. (BRL photos)

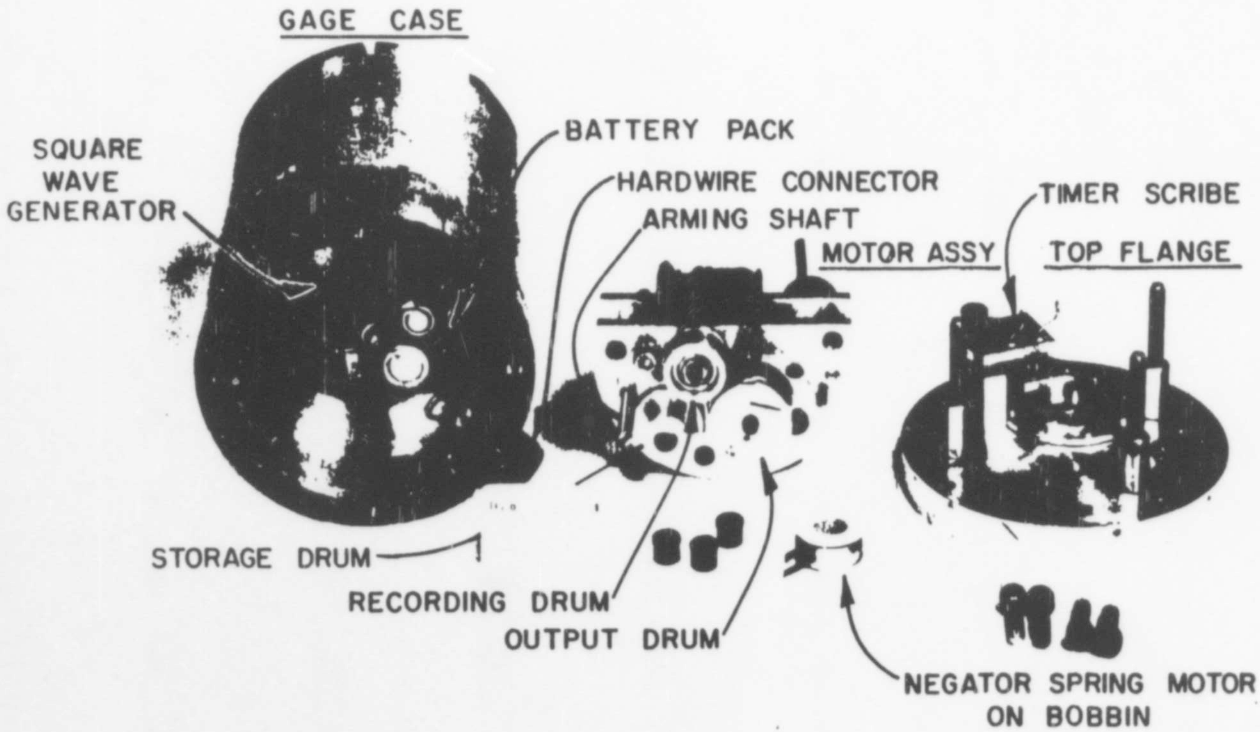


Figure A.26 Exploded view of PNS gage. (BRL photo)

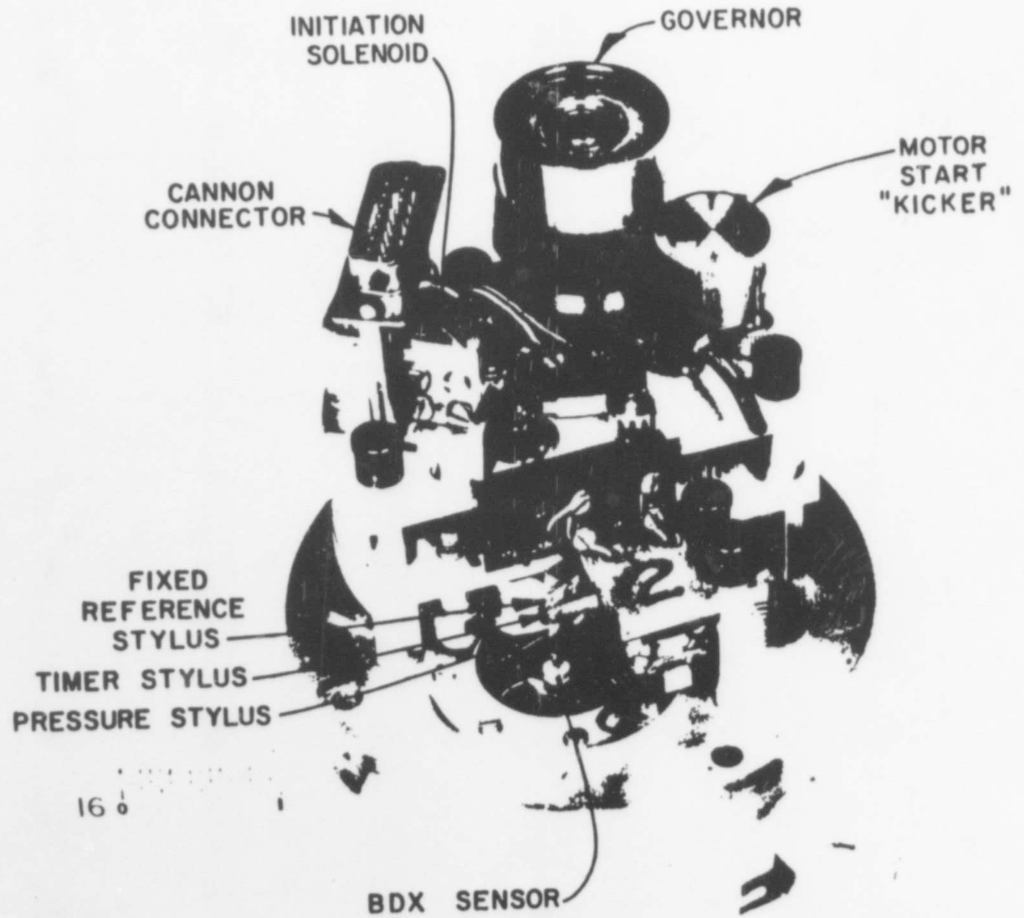


Figure A.27 View of PNS gage motor assembly. (BRL photo)

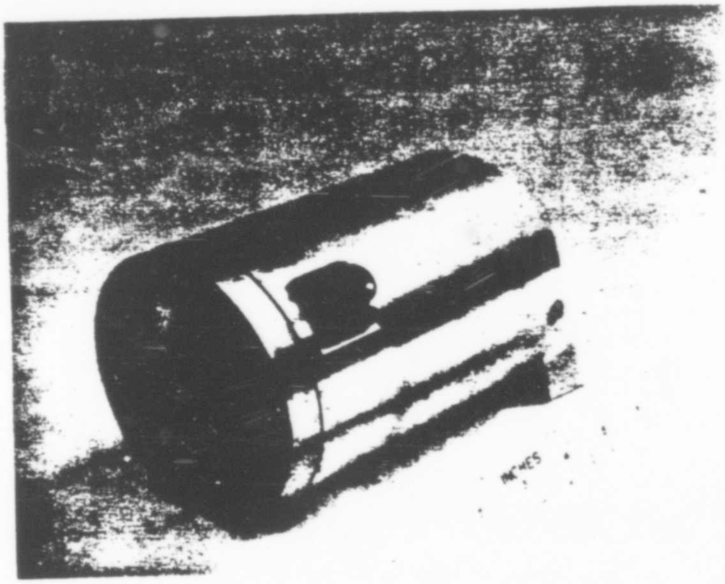


Figure A.28 Assembled view of PNS gage. (BRL photo)

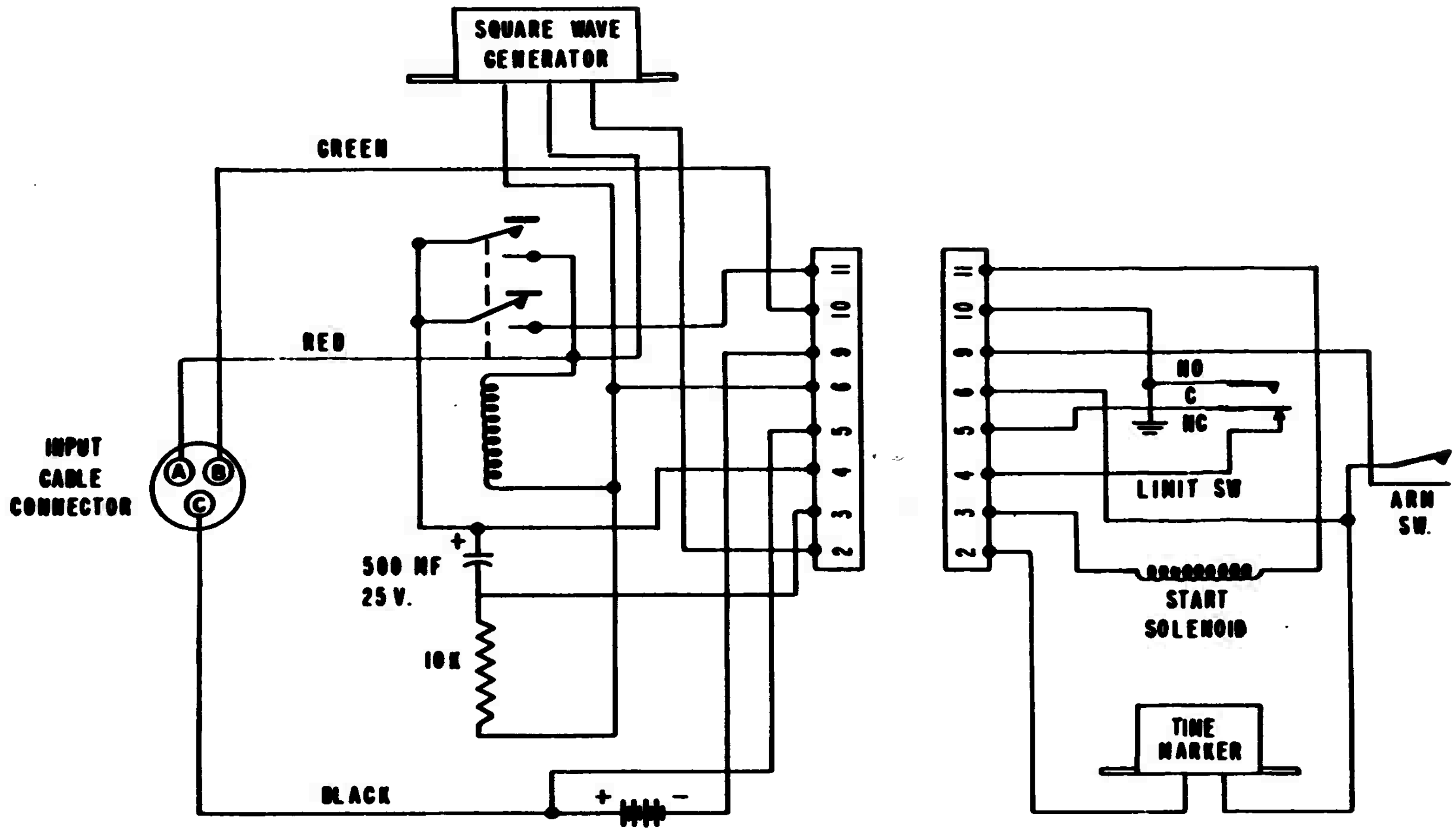


Figure A.29 Schematic of PNS gage circuit.

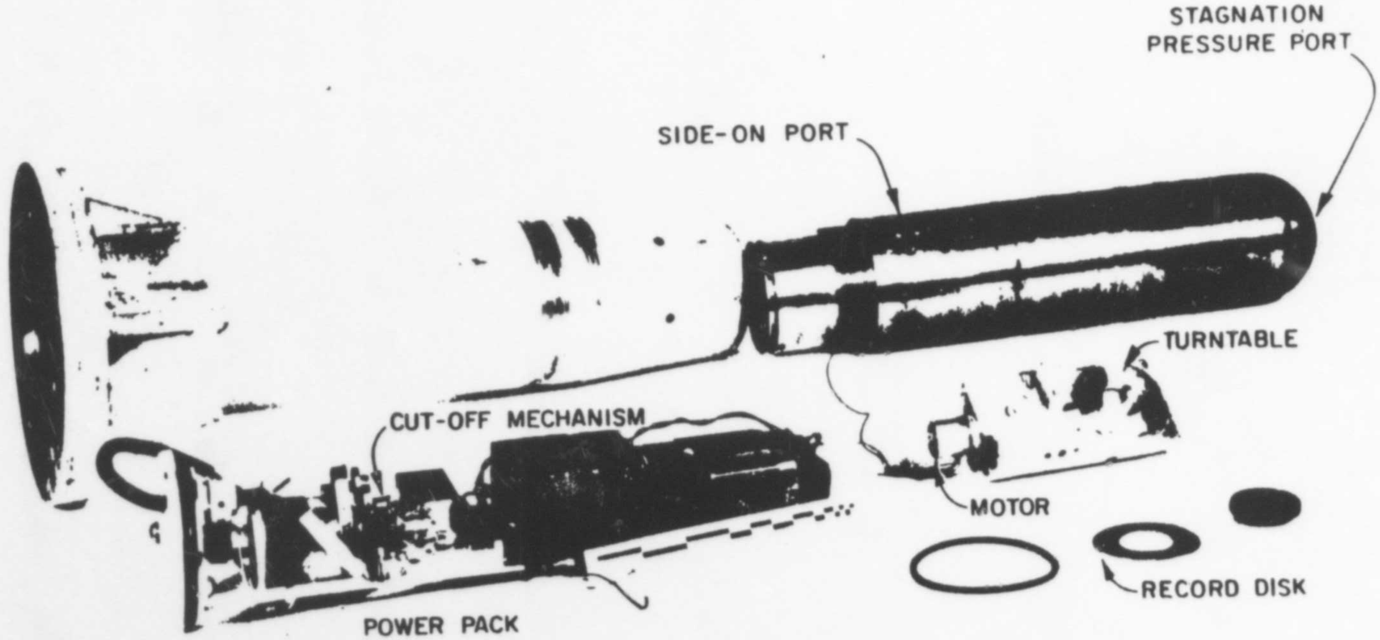


Figure A.30 Exploded view of QGS gage. (BRL photo)

Figure A.31 Assembled view of QGS gage. (BRL photo)

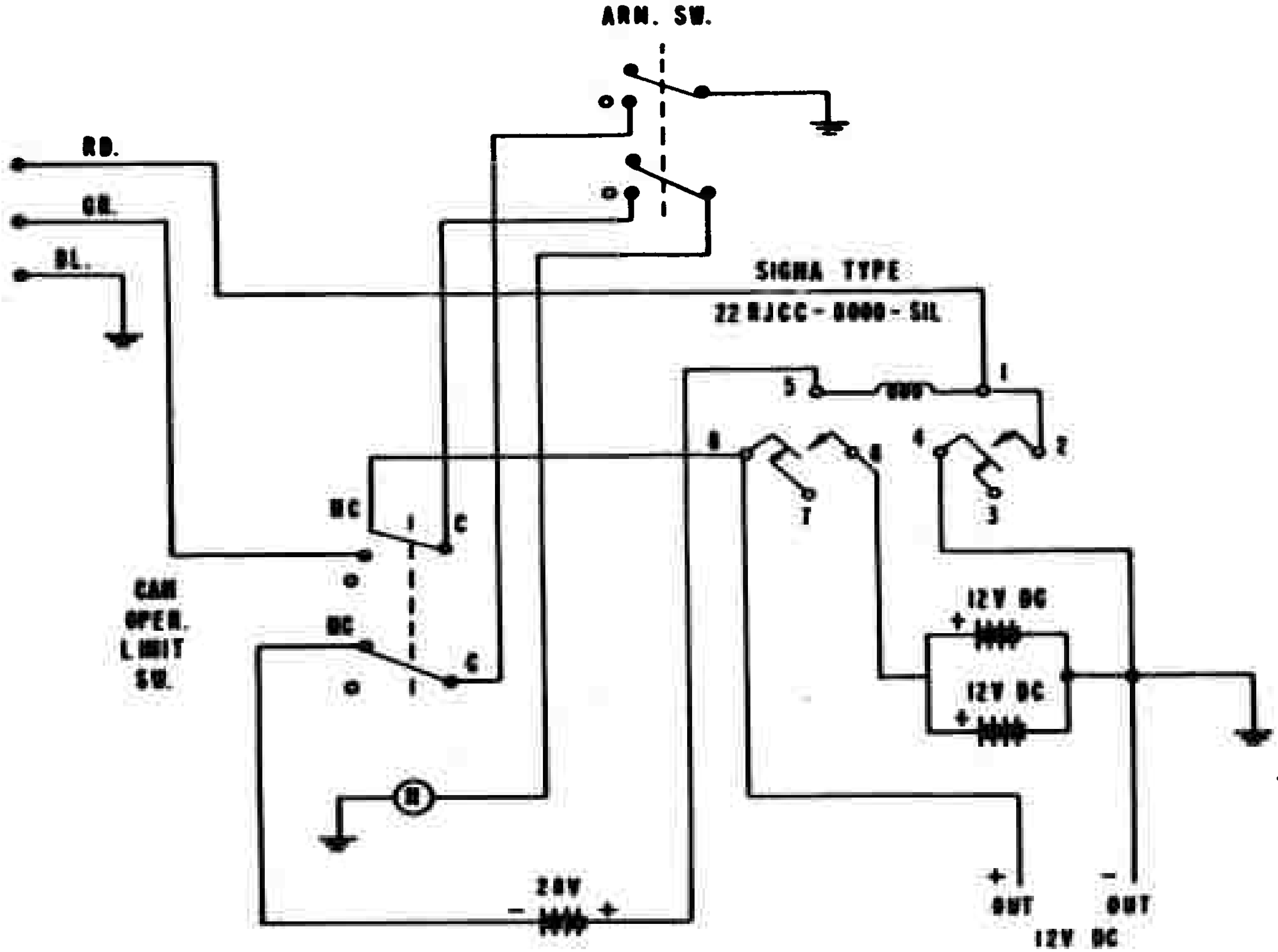


Figure A.32 Schematic of QGS gage circuit.

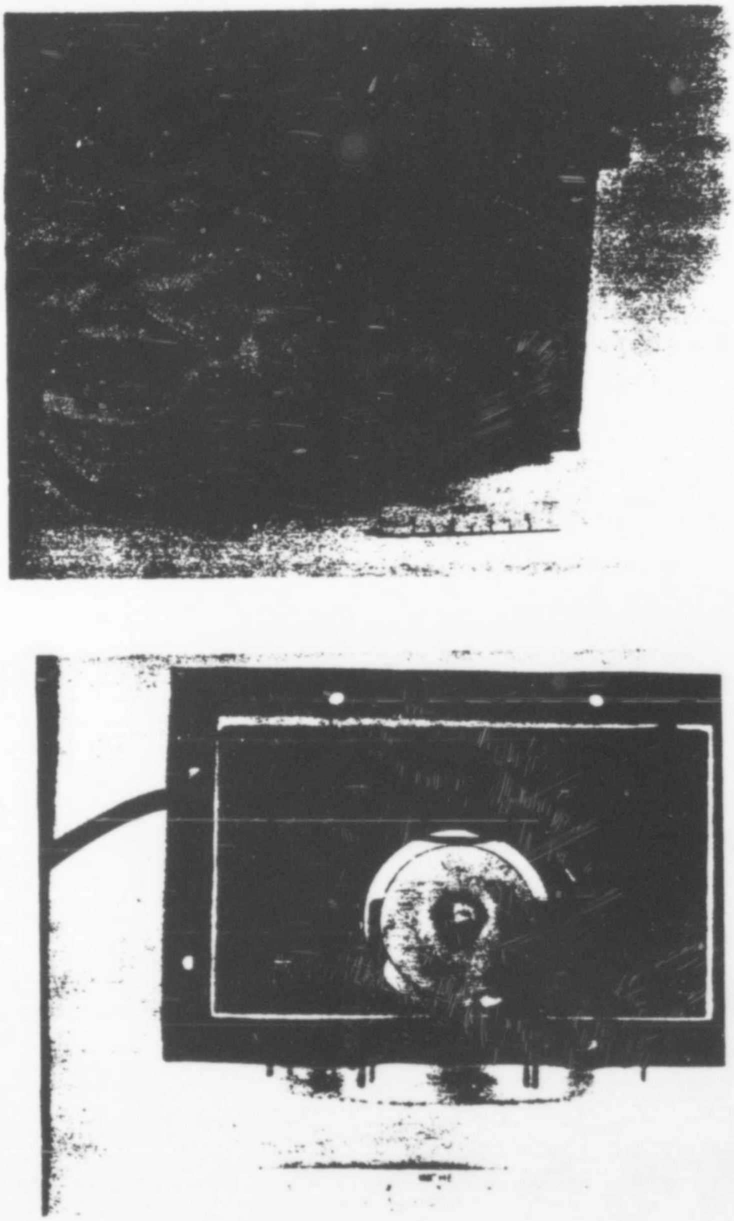


Figure A.33 Two views of VLP gage. (BRL photos)

Appendix B

PIEZORECORDING FOR PROJECT 1.1, SHOT SMALL BOY

George D. Teel

Prior to Shot Small Boy, it had been felt by this laboratory that recording by utilizing piezoelectric pressure transducers in a nuclear environment was impractical and, therefore, it had not been attempted. It was decided that two experimental piezoelectric recording systems should be operated on Shot Small Boy. There were two procedures which showed possibility and it was concluded that both should be attempted.

B.1 SELF-CONTAINED ONE-CHANNEL SYSTEM

The first system, a completely self-contained unit, was buried at Station 501.12, 380 feet from ground zero. The recording system consisted of a Tektronix Type 321 (battery-powered) oscilloscope, a General Radio Model 651AE oscillographic recorder, a cathode follower, a piezoelectric transducer, a Variac for camera speed control, a 24-vdc to 110-vac converter, a 24-volt storage battery, and a Webster Chicago type sequence timer. Figure B.1 shows a schematic of this recording system.

The oscilloscope and camera were mounted on a shock-mounted channel iron frame (Figure B.2), and housed in a 2- by 2- by 4-foot steel container. The channel iron frame was attached to a 2- by 4-foot piece of $^3/_4$-inch plywood. This frame was placed in the container on 2 inches of foam rubber.

The storage battery, converter, and sequence timer were mounted in a 2- by 2- by 4-foot plywood container. The steel container was buried at a depth of 6 feet and was covered by 4 inches of lead and 4 feet of sandbags and soil to protect the film from radiation exposure. The associated plywood container was buried alongside the recorder at a depth of $2^1/_2$ feet and was covered with sandbags.

The pressure transducer and mount (Figure B.3) were placed flush with the ground above the recording system. A nylon bushing between the gage and the mount served to isolate the transducer from its surroundings.

The pressure transducer and cathode follower utilized were of BRL design and manufacture.

B.2 TWO-CHANNEL SYSTEM

The second recording system was located in the 5.607 shelter, with the pressure transducers located at Station 501.16, 1,160 feet from ground zero. Two channels of recording were attempted on this system.

The equipment utilized for this system was identical to that of the one-channel system, with the exception of the oscilloscope which was a Tektronix Type 502 dual beam oscilloscope. Figure B.4 is a schematic of this system, and Figure B.5 is a photograph of the oscilloscope and camera in their relative positions of use.

For one channel of the recording, a piezoelectric transducer was connected to the A input of the amplifier, while a second cable was run from the gage to the oscilloscope but connected only to the B input of the amplifier and not to the gage. This amplifier was then operated in the A-B mode. It was assumed that any signal introduced into the cables by the nuclear environment would be the same for each cable (assuming the cables are run together for equal lengths) and therefore the A-B mode would eliminate any cable noise and yield only the transducer signal. The second channel employed an ordinary gage to cable to oscilloscope connection.

Here also, the gages were of BRL design and manufacture and were placed in an isolated mount.

B.3 RESULTS

B.3.1 Self-Contained One-Channel System. All the equipment survived the event satisfactorily. The oscilloscope did require the replacement of two transistors during recalibration following the event, but this damage had not rendered the apparatus inoperable. It is assumed that the sequence timer failed to accept the EG&G signal that would have initiated the camera run, and therefore no records were obtained from this system. Basis for this assumption is that some difficulty of this nature had been experienced in pretest dry runs, but it was thought that this defect was corrected.

B.3.2 Two-Channel System. All equipment in this system survived the event satisfactorily, and no defects in the apparatus have since been located. The records obtained were poorly focused, radiation exposed, and deflected off-screen, but some conclusions can be drawn. The record from the channel operated in the A-B mode returned to the zero baseline approximately 150 msec after shock arrival. An extrapolation of the portion of the record on the screen back to the shock arrival time gives an estimate of 10 psi for the shock front overpressure. The second channel, the direct recording system, yielded no usable information. Therefore, it can be concluded with some certitude that the differential subtraction method, A-B mode, has merit in this type of application where induced signals through the cables are anticipated.

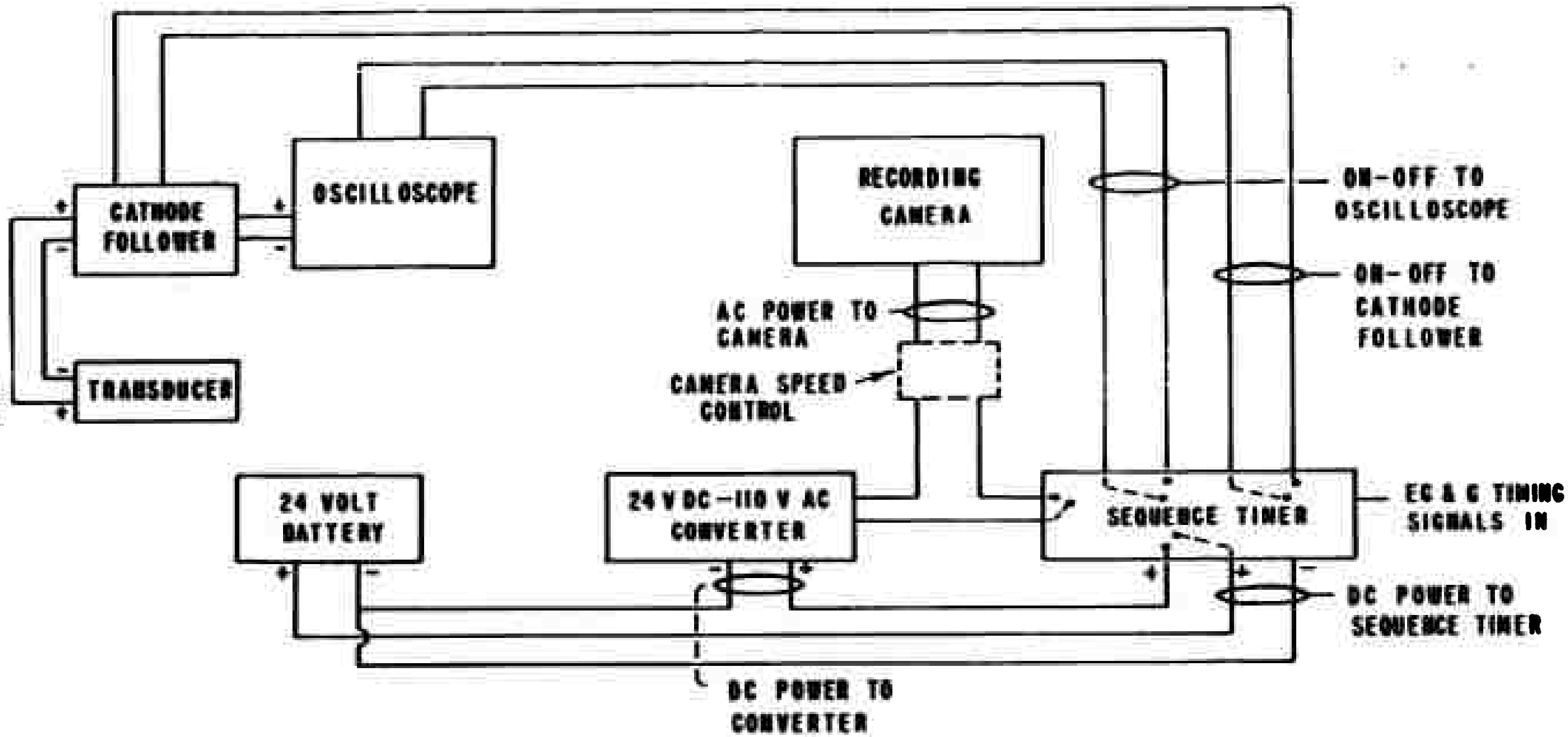


Figure B.1 Schematic of self-contained piezoelectric recording system.

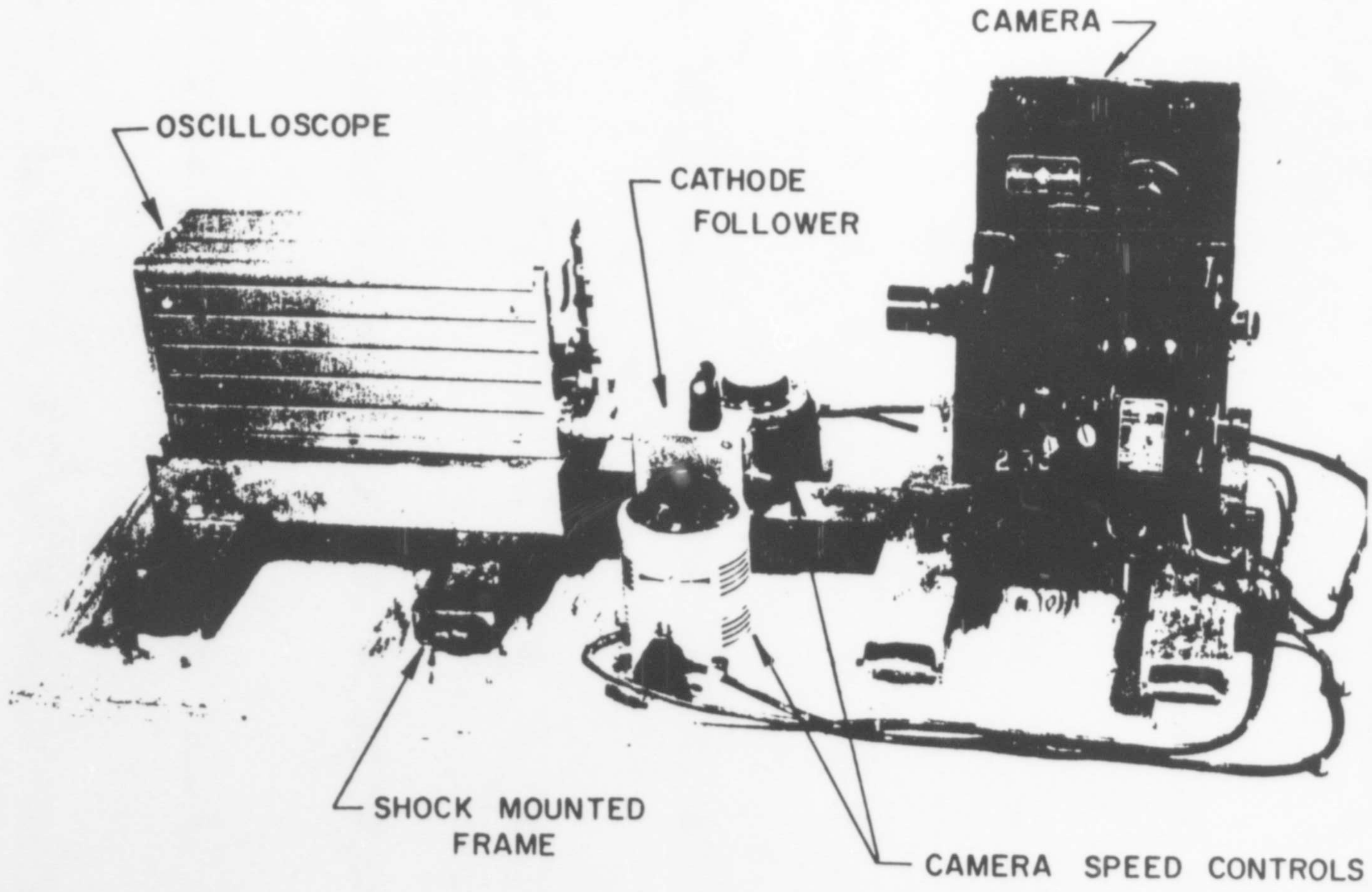


Figure B.2 Self-contained systems. (BRL photo)

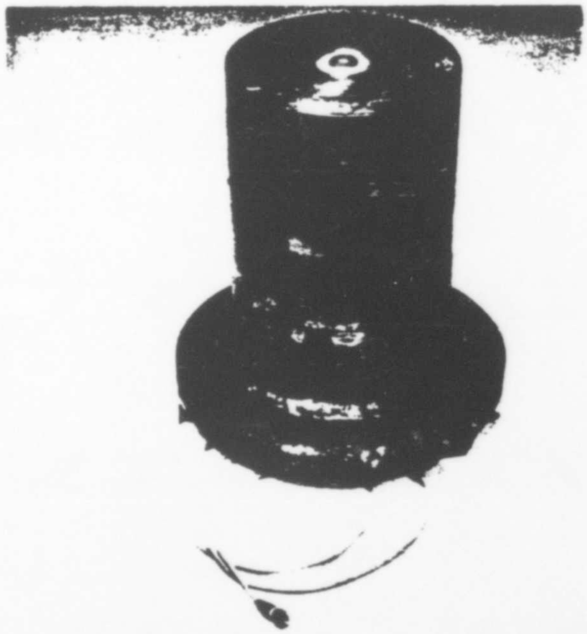


Figure B.3 Station 501.12 piezoelectric transducer and mount. (BRL photo)

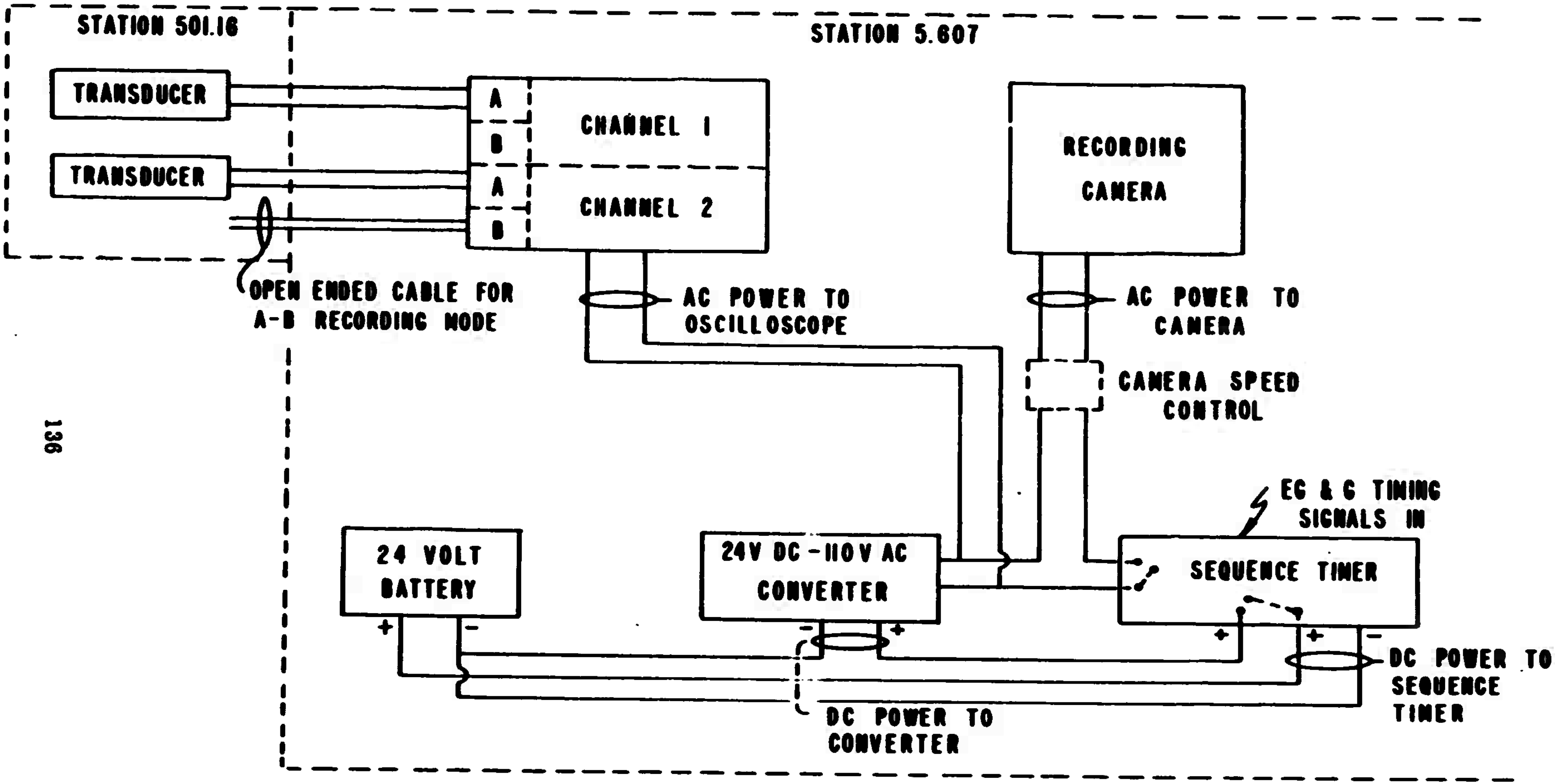


Figure B.4 Schematic of two-channel piezoelectric recording system.

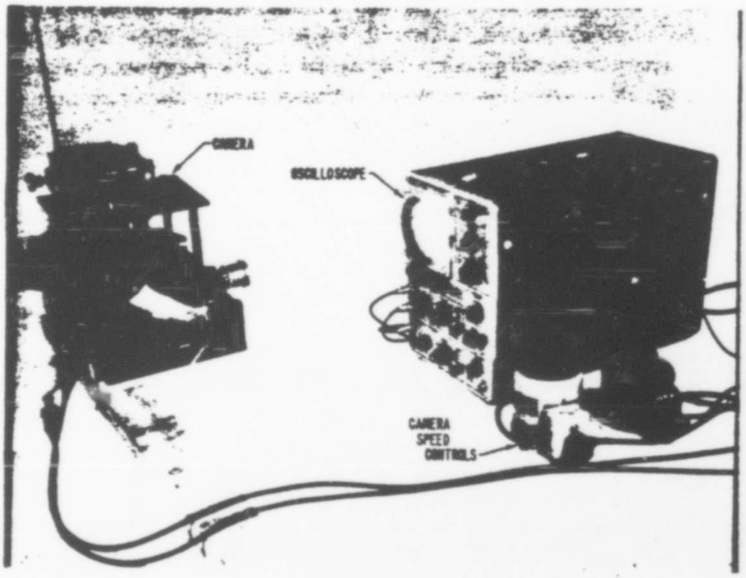


Figure B.5 Two-channel oscilloscope and recording camera. (BRL photo)

Appendix C

SHOCK-TUBE CALIBRATION OF PRESSURE TRANSDUCERS AND SENSORS

George D. Teel, Daniel P. Lefevre, and Robert L. Peterson

C.1 INTRODUCTION

Prior to Operation Sun Beam those transducers and sensors used were calibrated, fired upon, recorded, and evaluated, utilizing the BRL Shock Tube Facility. Two shock tubes were used to accomplish this task: they were the high-pressure shock tube and the 24-inch air-driven shock tube. Descriptions of these shock tubes are included in this appendix. Since the 24-inch air-driven shock tube is of the conventional type, only a brief description is given.

C.2 HIGH-PRESSURE PHASE

Blast line instrumentation for Operation Sun Beam was to be extended to the 10,000-psi region. This extension introduced a requirement for gage evaluation and calibration in pressure regions far in excess of those previously conducted at BRL.

C.2.1 Description of the High-Pressure Shock Tube. The high-pressure shock tube was an excellent laboratory instrument for this type of test. This shock tube is not capable of producing shock waves in the 10,000-psi region, but could be operated up to shock pressures of about 1,200 psi. Figure C.1 is a sketch of the high-pressure shock tube, and Table C.1 is a description of the shock tube in tabular form. Since the high-pressure shock tube is of a detonation type utilizing a mixture of hydrogen and oxygen as the driver medium, the shock front is followed by a flame front which provides a secondary benefit, that of gage exposure to a high-temperature environment.

C.2.2 High-Pressure Electronic Gages. In order to establish a feeling of reliability about gages to be used in field instrumentation, tests had to be performed under controlled laboratory conditions to calibrate and evaluate these gages.

These tests were conducted, utilizing both static and dynamic calibration techniques. The gages were first installed in a static calibrator of the type shown in Figure C.2. This calibrator consisted of a supply bottle, a precision regulator and associated interconnecting tubing, a dial manometer, and a fixture for connecting the gage to the calibrator. Pressure was then applied simultaneously to both the gage and the manometer. Generally, the pressure was applied in 20-percent steps from 0 to 120 percent of the expected shock pressure. The output from the gages for each of these steps was then recorded.

Once the gages were calibrated, they were mounted in the shock tube and fired upon. The results were then compared against a standard for reproducibility of wave shape and linearity of output. In all cases, the gages to be evaluated were compared to a piezoelectric monitor gage. These gages were recorded using a cathode follower, an oscilloscope, and a polaroid camera. This gage and recording system are pictured in Figure C.3.

Various types of pressure transducers were to be utilized in Operation Sun Beam and, therefore, each of these varieties had to be tested. All types of gages were to be used in both side-on and total-head configurations. Those gages which were to record pressure equal to or in excess of 100 psi were the ones considered in this evaluation. Four types of electronic recording gages, all of the strain bridge or variable reluctance types, were checked. They were, according to manufacturer, Wiancko, Detroit Control (Figure C.4a), Dynisco, and Micro-Systems (Figure C.4b).

Electronic gages that were to be used in side-on conditions in the 100- to 200-psi regions were mounted in a large port in the 24-inch section of the shock tube. Figure C.5 shows this port with four gages (Detroit Control, Dynisco, Micro-Systems, and Wiancko) mounted for testing. Gages which were to be used at pressures higher than 200 psi were mounted in the 8-inch section of the shock tube. Figure C.6 shows a drawing of one of the gages mounted in a port ready for testing in this section. The electronic gages which were to be used in the operation in a total-head or stagnation configuration were installed in the shock tube, utilizing the mount pictured in Figure C.7. Due to the size of the mount and probe, this phase of the testing had to be confined to the 24-inch section of the shock tube. Since flying debris and intense heat were to be expected in the field condition, a plug was placed in front of the gage to protect the transducer from these adverse effects. Holes through this plug and a small chamber between the gage face and the plug created a response problem for this type of mounting. It was necessary to determine a hole size for the plug large enough to allow rapid filling of the gage and, hence, high response for the record and yet small enough to stop debris impingement on the gage face. These hole sizes were calculated on the basis of prior knowledge of chamber fill rates and boundary layer growth within the holes. These stagnation probes were then installed in the shock tube and fired upon to check response times and validate these calculations. Approximately 100 shots were fired in the BRL high-pressure shock tube in conjunction with this test.

C.2.3 High-Pressure Self-Recording Gage Sensors. Self-recording gage sensors were tested in the high-pressure shock tube described in Section C.2.1 for pressures in excess of 100 psi. A self-recording PGS type gage was installed in the 22-inch test section for this purpose, Figure C.8. This gage was used with interchangeable flange plates to permit testing of all sensors. The gage was also shock-isolated from the tube in order to damp out some of the high acceleration effect produced by the firing.

A second consideration was the development of a proper orifice size and a damping coefficient for both the PHS-1S and PGS-1S shock-mounted gages as well as the unmodified single diaphragm gages.

An additional test involving the PGS type gage with a USG-D sensor was initiated in the 1,000-psi ranges of the 8-inch test section.

All tests were compared with a standard piezoelectric transducer. Evaluation of the records included peak pressure, wave shape, positive duration, rise time, and damping characteristics. Figure C.9 gives the pressure-time plots of selected sensors.

C.3 LOW-PRESSURE PHASE

C.3.1 Description of the Low-Pressure Air-Driven Shock Tube. Those gages which were to be used in the 100-psi and lower pressure levels were evaluated, using the 24-inch air-driven shock tube. A blind flange was added to the end of the tube to utilize reflected pressure for obtaining the 100-psi level. Figure C.10 is a sketch of this shock tube, and Table C.2 is a tabular description of the shock tube.

C.3.2 Low-Pressure Electronic Gages. The low-pressure gages, Detroit Control, Micro-Systems, and Wiancko, were mounted in the shock tube section (Figure C.11) and subjected to shock pressures comparable to those which were to be recorded in the field. These records were then evaluated in the same manner as those from the high-pressure phase.

One of the prime objectives of this phase of the evaluation was to determine the diameter of the orifice to be used in conjunction with the Wiancko gages. These orifices were chosen with the requirement that the gage record should not display an overshoot in excess of 7 percent.

The 24-inch air-driven shock tube has been, and will continue to be, a satisfactory and useful instrument to test those gages for use in the 100-psi and lower levels.

C.3.3 Low-Pressure Self-Recording Gage Sensors. Low-pressure tests were made in the BRL air tube, Section C.3.1, Figure C.10. A PHS gage was installed in the square test section where calibration data in the 0.5- to 30-psi range was obtained. For data up to 100 psi, a PGS type gage was installed in a blind flange bolted over the muzzle of the air tube. These gage installations are shown in Figures C.12 and C.13.

A second consideration was to investigate the optimum orifice size of the pressure inlet to the sensor and the ultimate determination of a damping coefficient.

All tests were compared with a standard piezoelectric transducer. Evaluation of the records included peak pressure, wave shape, positive duration, rise time, and damping characteristics. Figure C.9 gives the pressure-time plots of selected sensors.

TABLE C.1 DETONATION-DRIVEN SHOCK TUBE

Driver Section	8-inch diameter gun, 27 feet 7 inches long, rifling not removed, 4140 steel.
Driver Gas	Mixture of hydrogen and oxygen.
Diaphragm Material	Aluminum and mylar.
First Driver Section	8.25-inch diameter, 27 feet 2 inches long, 4140 steel, 2-inch diameter; test ports located (two each opposing one another) at 9, 16, and 21 feet from the diaphragm, 28-degree conical nozzle machined into the end of this section.
Second Driven Section	22.121-inch nominal inside diameter, variable in length from 58 to about 155 feet; outside diameter 24 inches, commercial seamless wrought steel. Two $2\frac{1}{2}$-inch diameter test ports opposing each other at 18 inches and two at 56 inches from the nozzle end. Two test ports 4 by 18 inches opposing each other, normally at 55 feet from the nozzle. Section lengths are random from 19 to 24 feet.
Total Tube Length	Variable from 113 to 213 feet.
Overpressure in First Driven Section	Maximum of 1,200 psig.
Overpressure in Second Driven Section	Maximum of 180 psig.

TABLE C.2 DESCRIPTION OF 24-INCH SHOCK TUBE

Item	Configuration
Type	Cold gas driven with air, helium, or nitrogen.
Size	24-inch OD, 22⅝-inch ID, 0.69-inch thick wall.
Material	Seamless steel pipe.
Inside Finish	Bitumastic lining.
Driver Sections	1, 3, 6, 10, 36, or 55 feet long.
Driver Pressure	Maximum of 220 psig for 55-foot driver.
Total Length	Approximately 300 feet.
Diaphragm Material	1. Cellophane, 1½ mil. 2. Mylar, 5 and 7½ mil. 3. Lumerith, 3 and 10 mil. 4. 2 SO aluminum, 0.020, 0.032, 0.040, and 0.064 inch.
Rupture Method	Rod plunger driven with an air motor.
Name	**Description of Test Sections**
1. 20- by 20-inch Section	1. Square, 20 by 20 inches inside dimensions, 24 ST aluminum, mill finish, 16 feet long with 2-inch-thick walls. Center of section is 100 feet from diaphragm. Seven access ports: two 12 by 12 inches; one 9-inch diameter; and four 1⅞-inch diameter.
2. 24-inch OD Section	2. 22⅝-inch ID, seamless steel pipe, bitumastic lining, 10 feet 8 inches long with 0.69-inch wall. Center of test section 111 feet from diaphragm. Twelve access ports: three 2 by 8 inches; three 2 by 12 inches; three 4 by 16 inches; and three 3¼-inch diameter.
3. 4- by 4-foot Section	3. Square, 4- by 4-foot inside dimensions, steel plate, ½-inch-thick walls, aluminum painted inside. Total length: 58 feet plus 6 feet transition from 24-inch shock tube. One 16-foot transition section, one 20-foot length, two 10-foot lengths, and two 4-foot lengths. Four access ports, 2 by 2 feet in each 4-foot length. Four 1-inch thick, 17½-inch-square herculite windows.

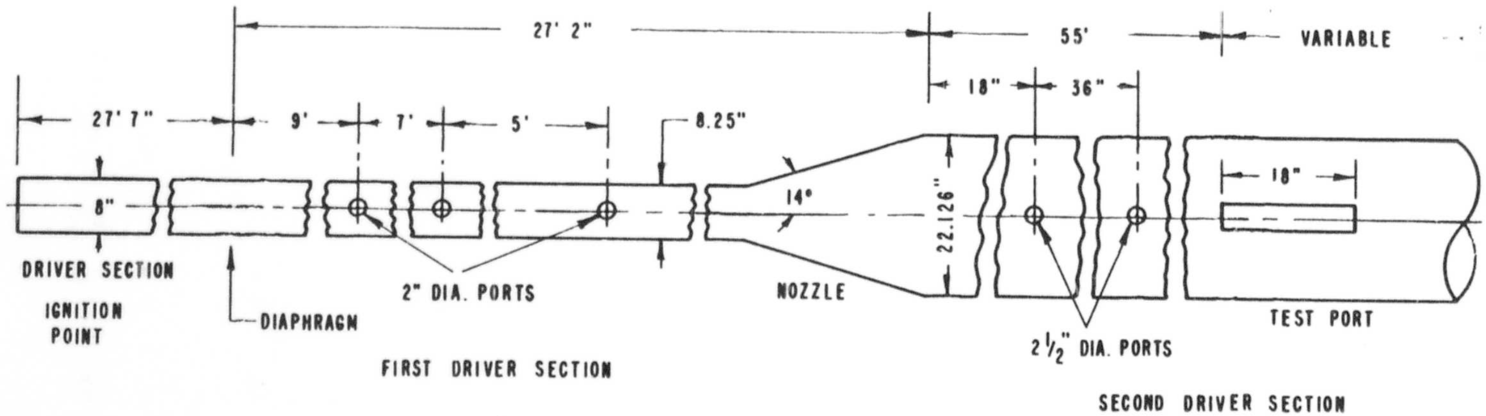


Figure C.1 Sketch of high-pressure shock tube.

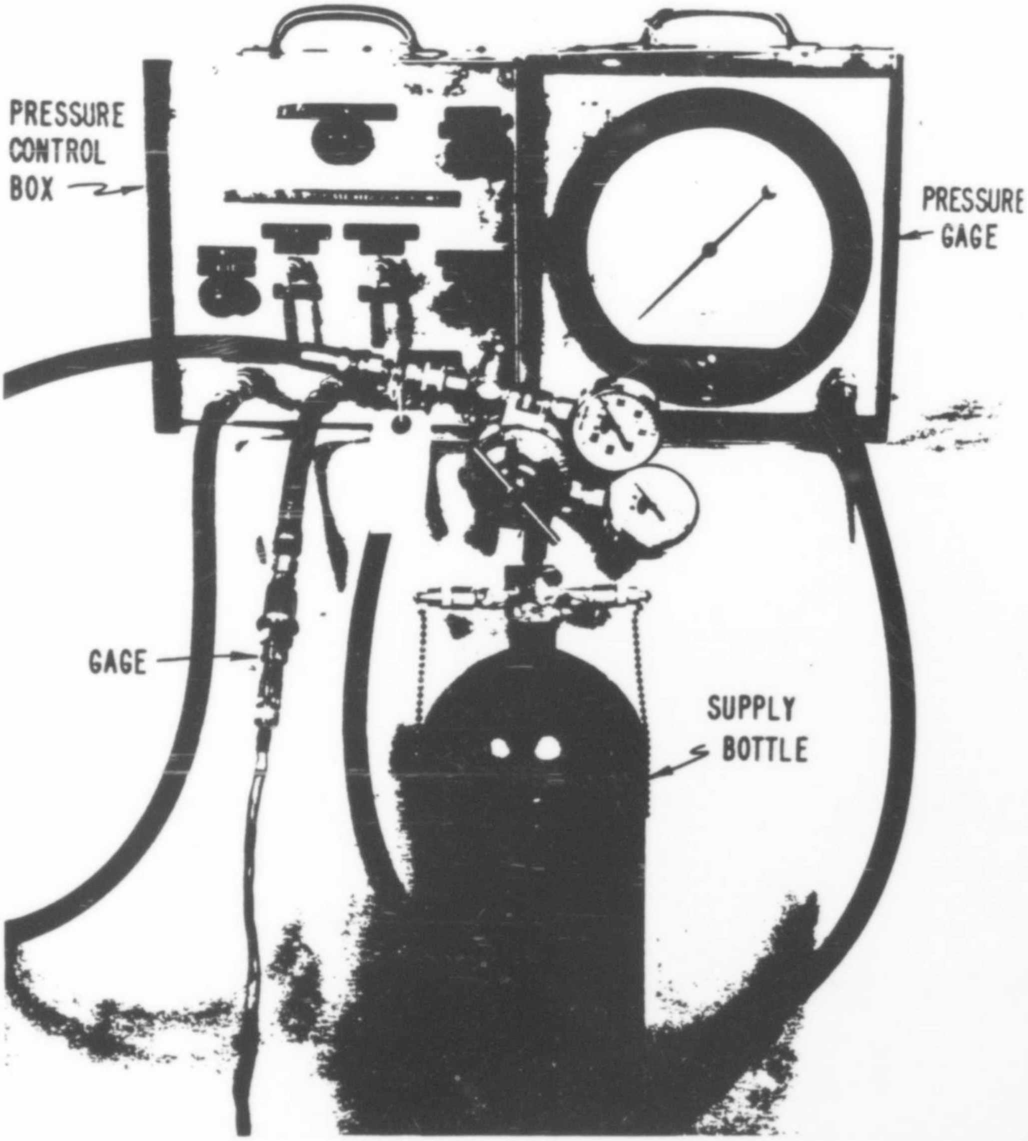


Figure C.2 Static calibration apparatus. (BRL photo)

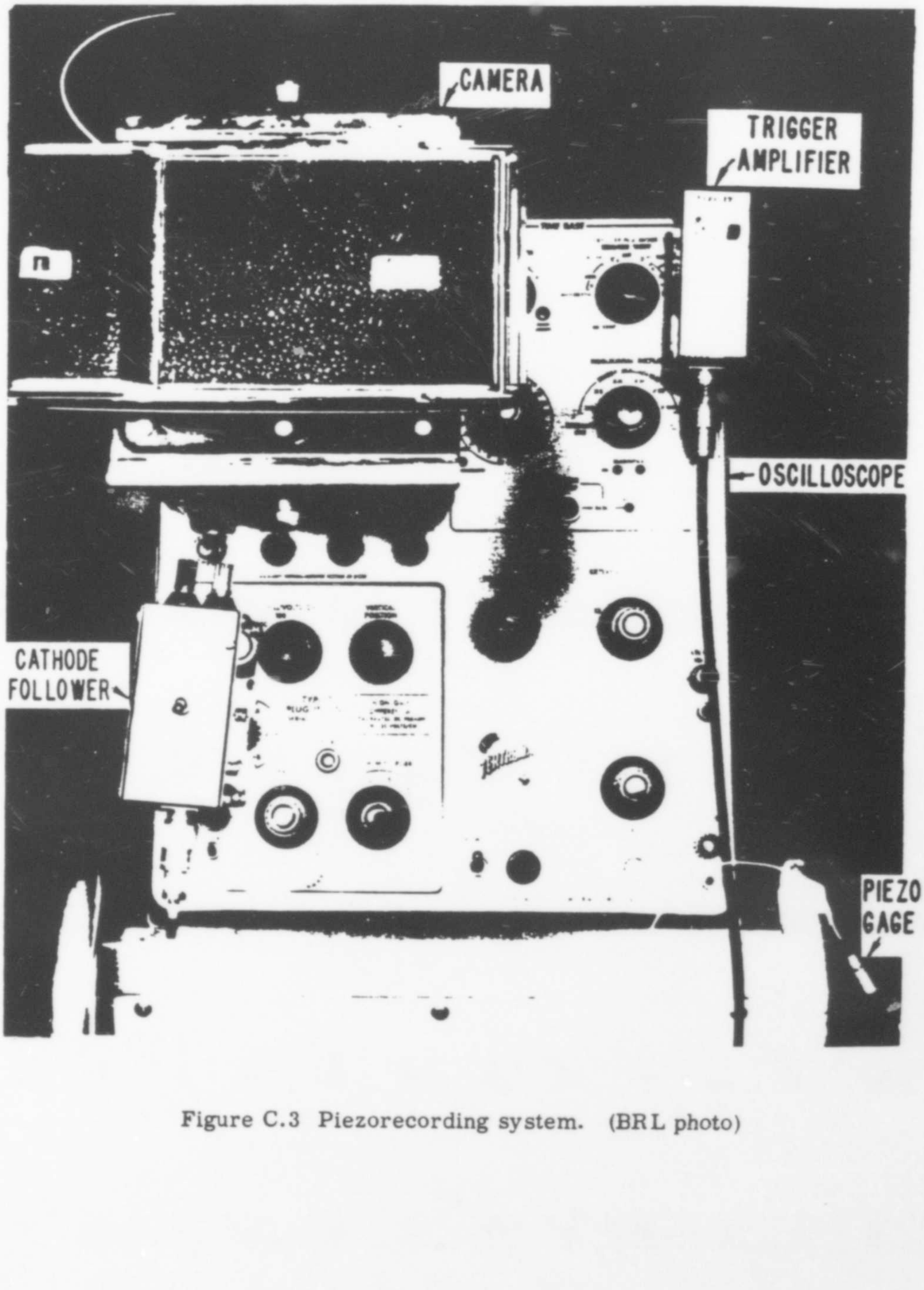
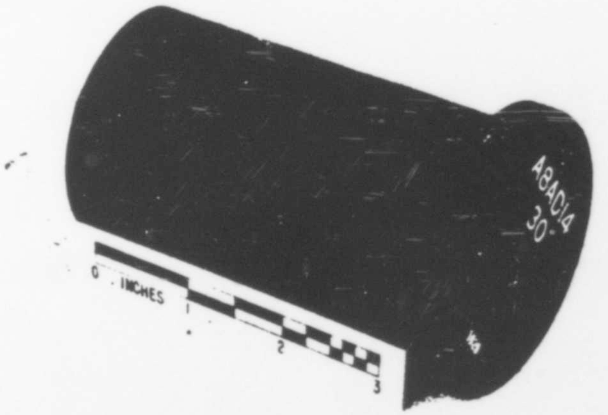


Figure C.3 Piezorecording system. (BRL photo)

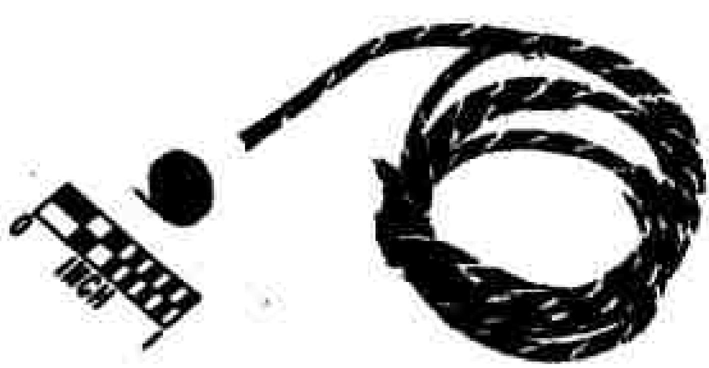
Detroit Control



Wiancko

Figure C.4a Electronic pressure gages, Detroit Control and Wiancko. (BRL photos)

Dynisco



Micro-Systems

Figure C.4b Electronic pressure gages, Dynisco and Micro Systems. (BRL photos)

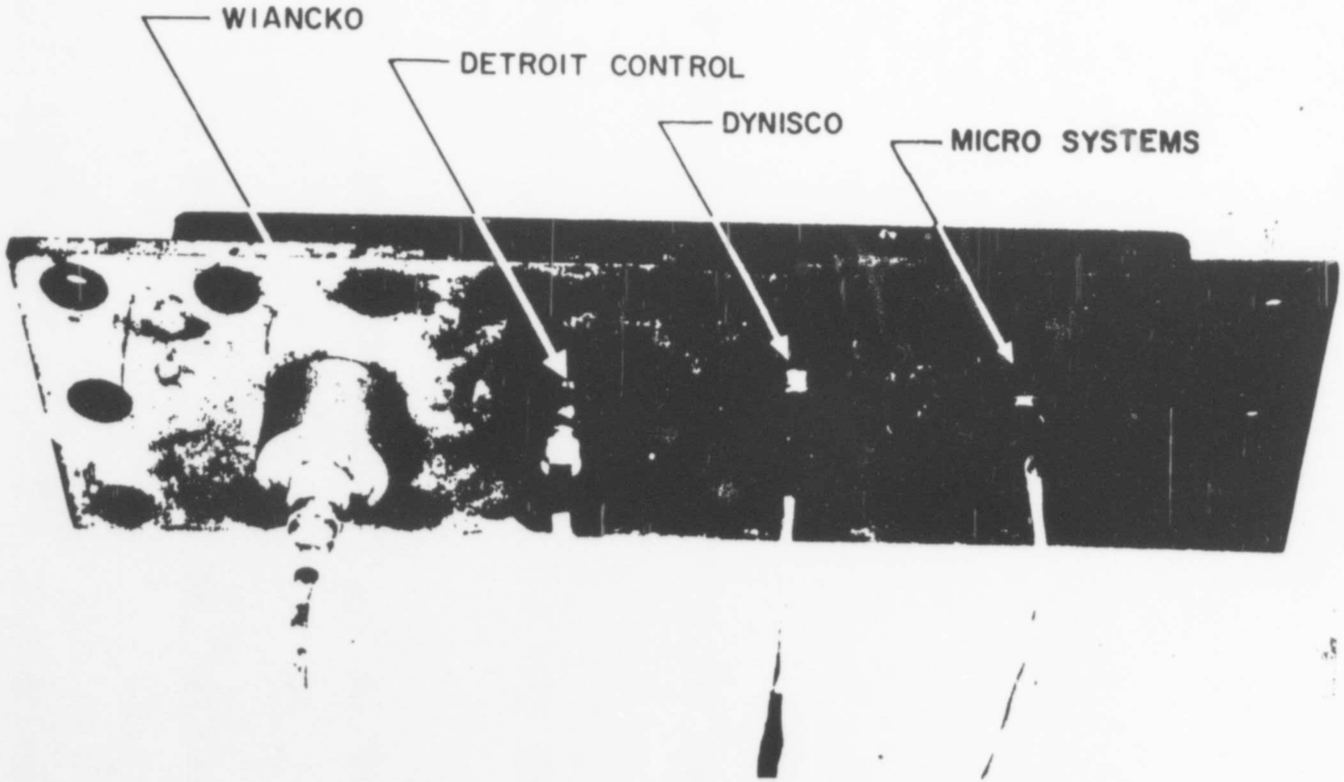


Figure C.5 Port from 24-inch test section of high-pressure shock tube with gages mounted. (BRL photo)

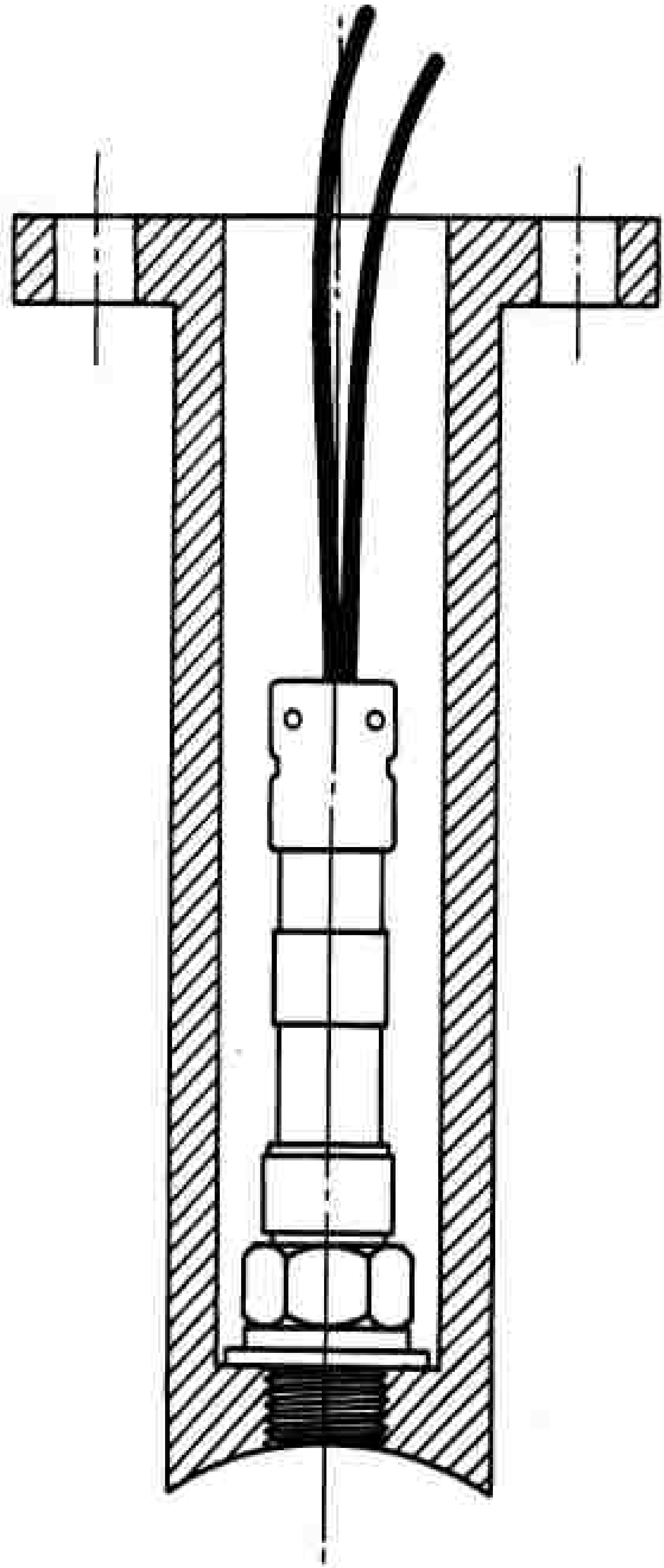


Figure C.6 Sketch of port from 8-inch section of high-pressure shock tube with gages mounted.

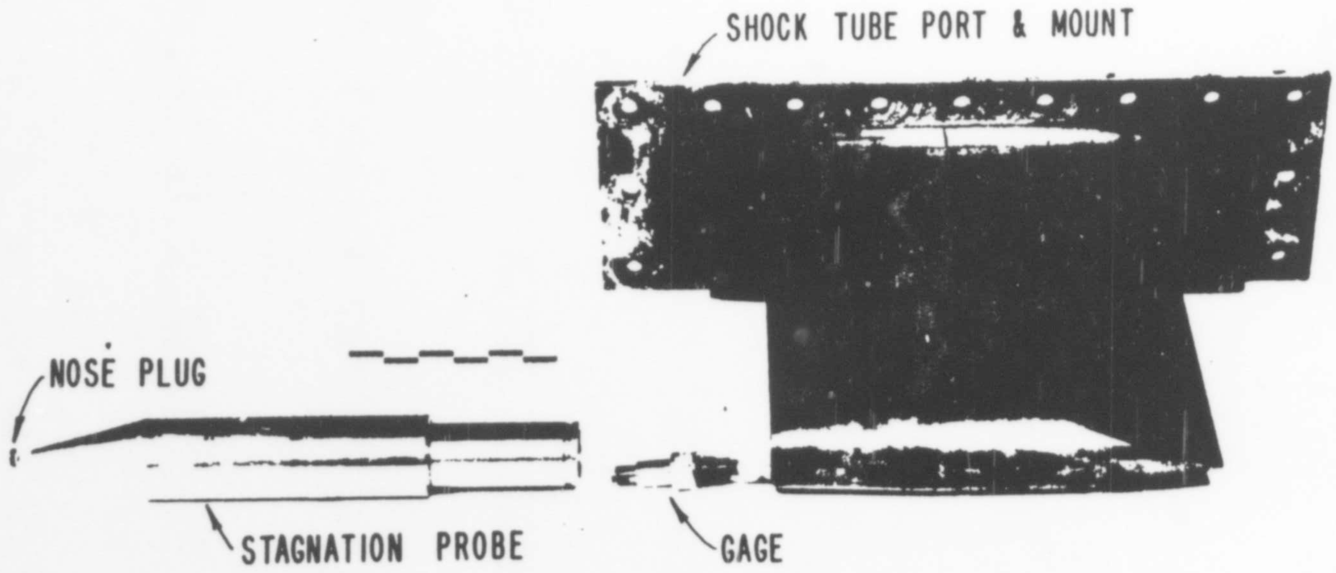


Figure C.7 Stagnation probe showing gage, mount, and shock-tube port. (BRL photo)

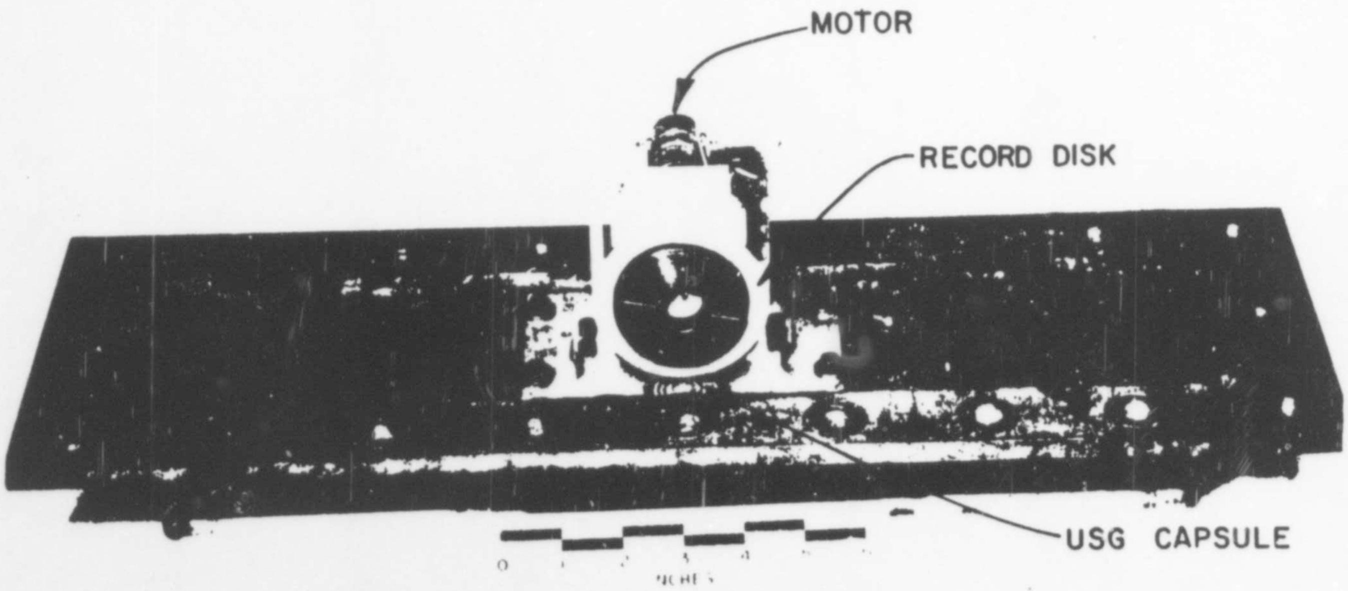


Figure C.8 PGS type gage in high-pressure mount. (BRL photo)

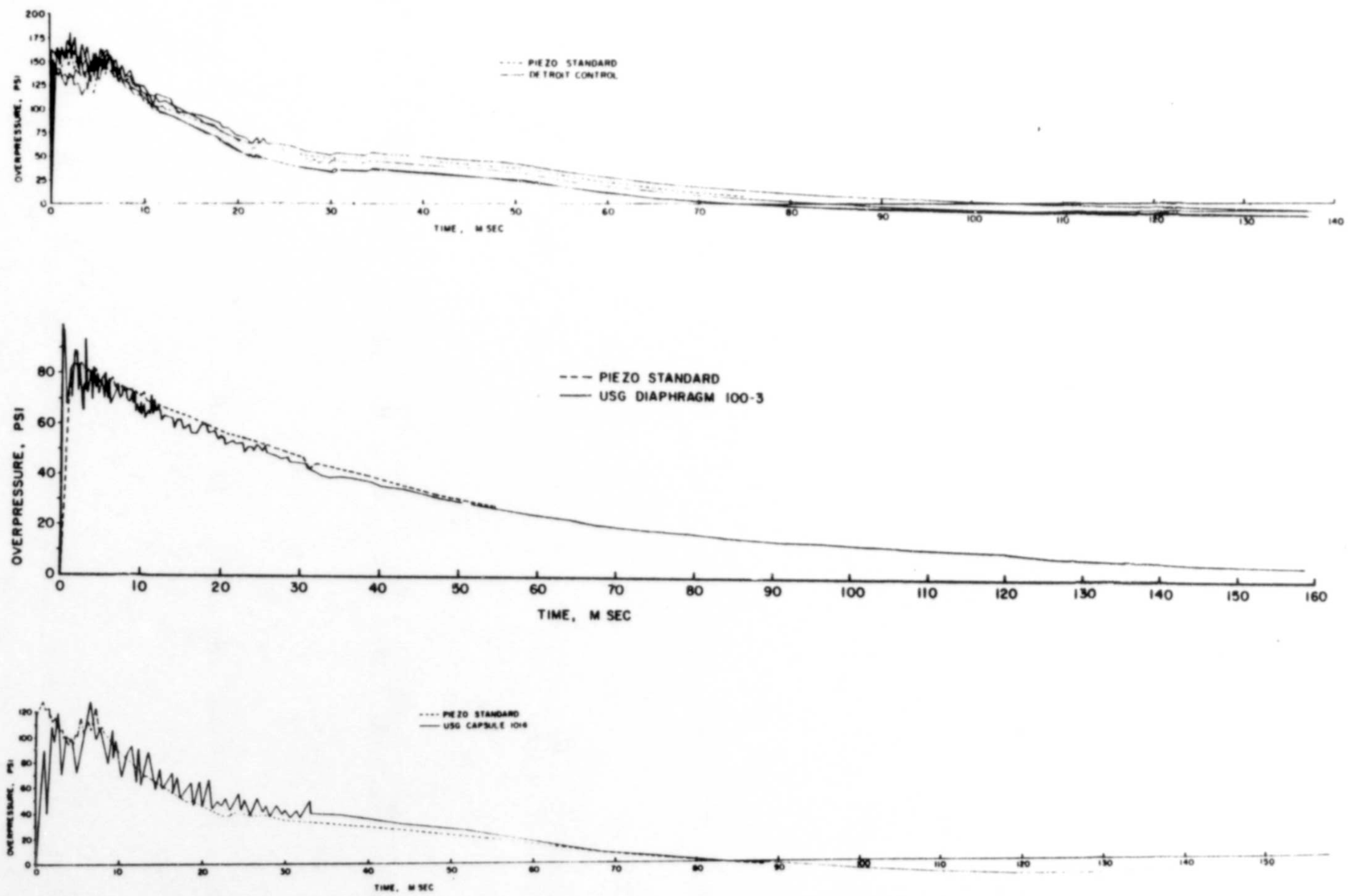


Figure C.9 Pressure-time plots.

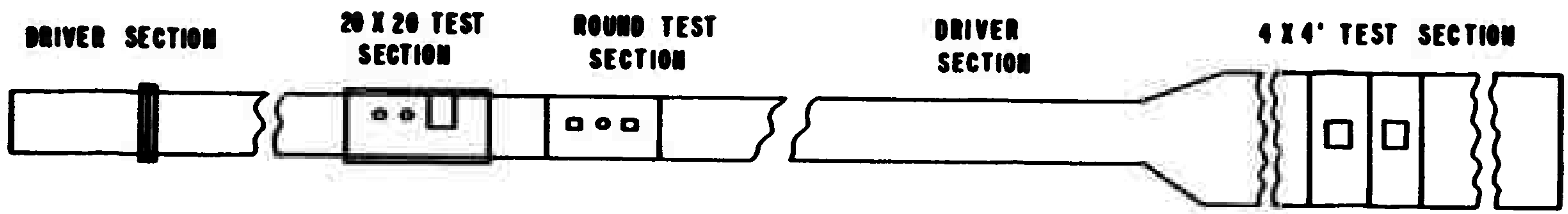


Figure C.10 Sketch of low-pressure shock tube.

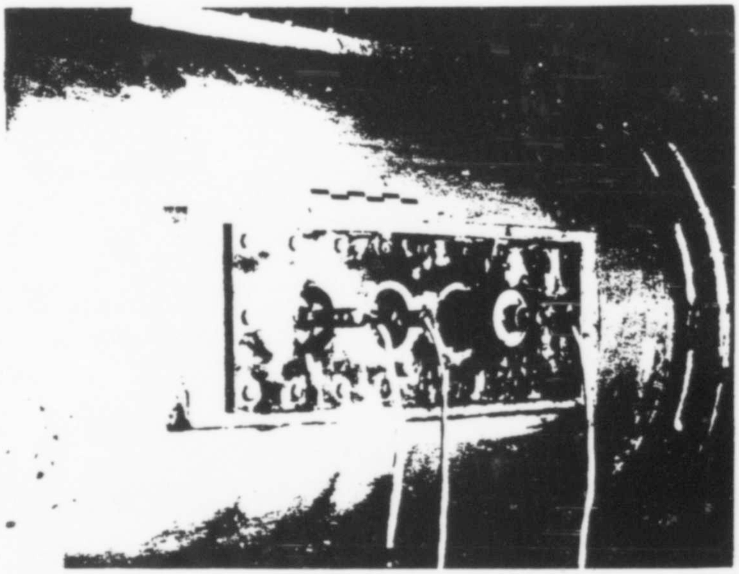


Figure C.11 Low-pressure tube test section showing port with gages mounted. (BRL photo)

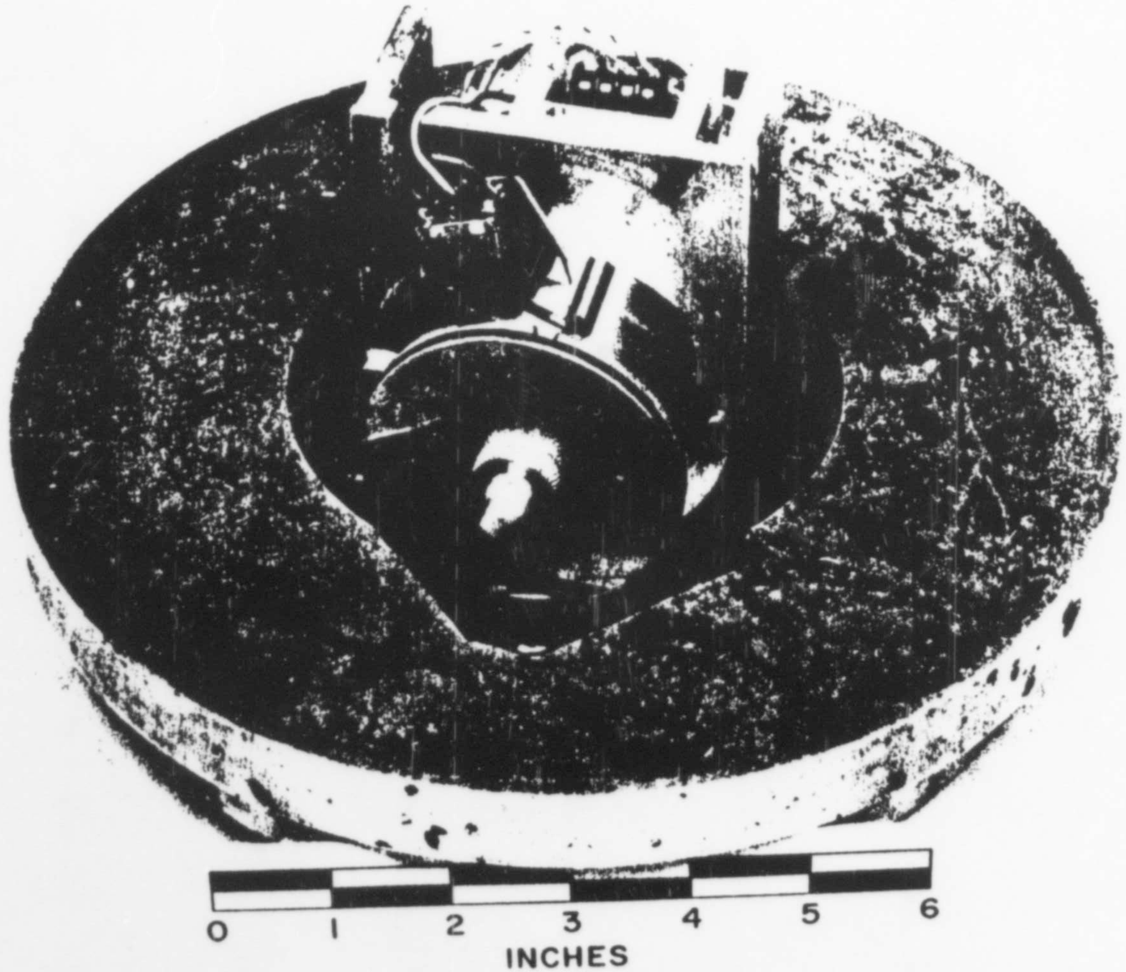


Figure C.12 PHS gage in square test-section mount. (BRL photo)

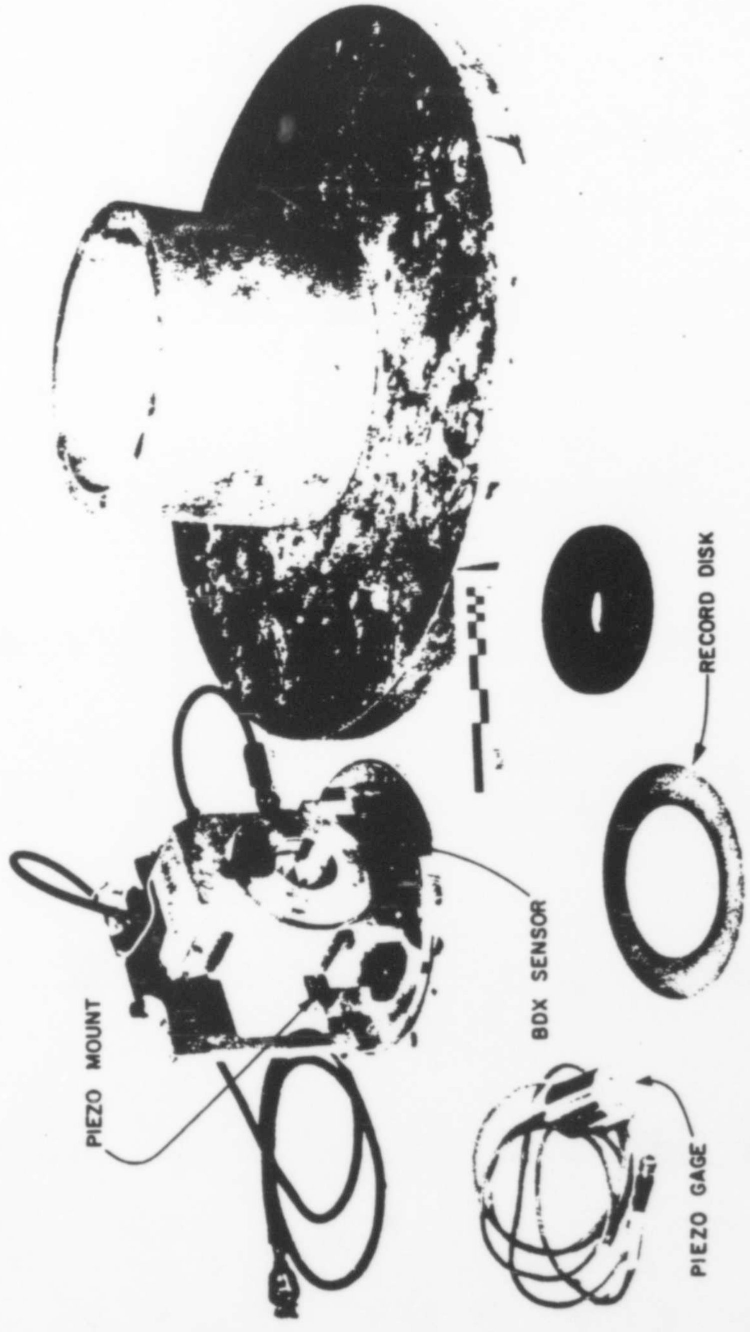


Figure C.13 PGS type gage and blind flange mount. (BRL photo)

Pages 157 through 170
deleted.

REFERENCES

1. J. F. Moulton, Jr.; "Nuclear Weapons Blast Phenomena"; DASA-1200, Volume II, March 1960; Defense Atomic Support Agency, Washington, D.C.; Secret Formerly Restricted Data.

2. E. J. Bryant and J. H. Keefer; "Basic Airblast Phenomena"; Project 1.1, Operation Plumbbob, WT-1401, June 1962; Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland; Confidential Formerly Restricted Data.

3. E. G. Schwartz, R. E. Reisler, and J. H. Keefer; "Structures Instrumentation"; Project 3.4, Operation Sun Beam, Shot Small Boy, POR-2225, 14 June 1963; Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland; Confidential Formerly Restricted Data.

Page 173 deleted.