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Project Officer's Report—Project 3.4

Structures Instrumentation

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This report ~~is a~~ discuss~~ion of~~ the measurement techniques and procedures used by BRL to obtain the loading and response data from structural designs of several agencies on Operation Sun Beam. Project objectives

The objectives of this project were: (1) to provide supporting instrumentation for pressure versus time, acceleration versus time, displacement versus time, stress versus time, and deflection versus time measurements for structures projects; and (2) to obtain data on air blast or ground shock required to properly analyze the results of the structures projects.

The instrumentation used ~~utilized~~ to obtain data in support of the requesting agencies was adequate to accomplish the objective. Modifications to the instrumentation procedure to gain improved results are desired.

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SHOT SMALL BOY

PROJECT OFFICERS REPORT – PROJECT 3.4

STRUCTURES INSTRUMENTATION

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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.

ABSTRACT

A description is given of the instrumentation employed by the Ballistic Research Laboratories for the Small Boy event of Operation Sun Beam. Free field air blast and structural response measurements were obtained for Projects 3.1, 3.2, 3.3, 7.2, and 27 using self-recording and electronic instrumentation. Self-recording gages and the electronic recording instrumentation are described; electronic transducers for obtaining acceleration, displacement, and strain are described by the respective structures projects.

A tabulation indicating success of the recording operation and a discussion of anomalies are presented. Photographs of the pressure versus time plots of the self-recording gage records are presented in Appendix B.

Results of the field testing of scale model domes are presented in Appendix C.

PREFACE

Project 3.4 was instituted as an instrumentation project to provide measurements for other DASA projects. By consolidating recording, fewer cable trenches and recording shelters were required.

This report is organized as a complete and detailed description of the BRL instrumentation program.

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CHAPTER 1

INTRODUCTION

This report is a discussion of the measurement techniques and procedures used by Ballistic Research Laboratories (BRL) to obtain the loading and response data from structural designs of several agencies on Operation Sun Beam.

1.1 OBJECTIVES

The objectives of Project 3.4 were twofold:

(1) To provide supporting instrumentation for pressure versus time, acceleration versus time, displacement versus time, stress versus time, and deflection versus time measurements for structures projects;

(2) To obtain data on air blast or ground shock required to properly analyze the results of the structures projects.

1.2 BACKGROUND

The quality and value of the results of full-scale field testing of structures are directly dependent upon the instrumentation on the structures. An additional requirement is an accurate knowledge of the free-field blast and shock input parameters to the structure. This project provided the maximum support feasible, within a short time period, to several projects in the form of measurements of the transient loading and response of test structures. BRL has, on a large scale, provided supporting measurements since Operation Upshot-Knothole. In full-scale testing, it is essential to use reliable and well tested instrumentation to insure the obtaining of the desired measurements.

Chapter 2

OPERATIONS

2.1 INSTRUMENTATION

Electronic instrumentation was used mainly for response measurements of Project 3.3. In addition to input free-field pressure (part of blast line Project 1.1) requirements at the structure locations, various pressure, acceleration, displacement, and strain measurements were instrumented on the various structures as tabulated in Table 2.1 (Structure locations are shown on Figure 2.1). Detailed structures and blast line transducer locations are shown in the 3.3 and 1.1 reports.

Self-recording pressure gages as described under Section 2.3 were used to obtain pressure time histories for Projects 3.1, 3.2, 3.3, 7.2, and 27. Four gages were located along a line in the free-field adjacent to the Project 3.1 dome installations. For Project 3.2, one self-recording gage was located in each of the projects two structures, Stations 515.01 and 515.02. Gages for 3.3 were a part of the Project 1.1 blast line. Ten gages were provided for Project 7.2; one gage was located in the free-field and one gage inside the test structure at each of five stations. Three gages were installed along a line in the free-field for Project 27 (LRL).

A cadmium sulfide photocell initiator was used to initiate all gages for Projects 3.1 and 7.2. Those gages used for Projects 3.2 and 27 were hard-wire initiated, using EG&G -2 second timing signals. A -1-second timing signal backed up the -2 second signal. Under normal circumstances, the photo-initiators would not have been used; however, they were necessary due to the final location of the projects, the non-availability of timing signals at these locations, and the possible interference signal wires might present to the electromagnetic pulse measurements. Table 2.2 summarizes the self-recording instrumentation. Figures 2.2 to 2.6 show the layout for the instrumentation.

2.1.1 Instrument Shelter Requirements. Electronic recording instruments with the 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 width of the building was 25 feet. 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 signal cables to each instrument. See Figures 2.7, 2.8, and 2.9.

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 (see Figures 2.10 and 2.11).

During the preparation phase, a ramp led to an end door in the shelter. The shelter was air conditioned, with an air lock door preventing extensive dust intrusion.

Shelter power for lighting, battery charging, air conditioning, and electronic instruments was furnished by an external generator. During the event, power was obtained solely from batteries.

The final button-up phase of the shelter operation, beginning at D-2 days and continuing through D-1, consisted of sand bagging the ramp doorway, removing the generator, and covering the top hatchway with its protective layer of sand bags.

2.2 ELECTRONIC RECORDING

2.2.1 System Details. The recording shelter contained all electronic instrumentation for Project 3.3, in addition to the major portion of instrumentation for blast line measurements. All channels of instrumentation for Project 3.3 were recorded by Consolidated Electrodynamics Corporation (CEC) 3-kc carrier systems (See Figure 2.12), displaying the transducer outputs through galvanometer traces onto photo-sensitive paper. All input pressure measurements made from variable-reluctance gages were likewise recorded by 3-kc carrier systems. A total of 72 channels of this type were utilized. The recording systems were all of standard commercial varieties, adapted for use to field tests. The 3-kc systems are capable of 0 to 500 cps response.

2.2.2 Input Circuitry. The 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 added 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. BRL designed the circuitry for the carrier systems and contracted its fabrication to the Magnetic Instruments Corporation. (see Appendix A).

2.2.3 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. Various hard wire timing signals from Edgerton, Germahausen & Grier 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 units functioned as follows:

1. The -30 minute warm-up signal provided by EG&G initiated the logic unit which started the converters and connected dc power to the dc-driven recorders. The converters provided ac power to the ac systems.

2. The -15 second signal started the timing motor in the logic unit and the recorders. The present timing motor initiated the pre-and postshot electrical signals and determined the time of recorder run before shutoff (see Appendix A).

3. The -30 minute, -15 second signals were backed up by -15 minute, -5 second EG&G signals, respectively.

2.2.4 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 all transducer signal lines during the electromagnetic pulse phase of the event. The EG&G -2 second signal initiated the relays for signal line grounding (see Figure 2.13). Blue box relay contacts, in the grounding relay coil power circuit, were open at TZ, thus restoring the signal lines to normal. The several millisecond delay in the blue box circuit was intended to allow sufficient time for the electromagnetic pulse to diminish before the signal lines were connected.

Transducer 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 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 recorders by driving a galvanometer directly from a solar cell exposed to the flash.

Timing was furnished to all paper recorders by driving the galvanometers with a precision set oscillator of 1,000 cps.

2.2.5 Transducers. Accelerometers, displacement gages, pressure transducers, and strain gages used in Project 3.3 structures are reported under that report. Pressure inputs to these structures, measurements along the blast line, were made with the Wiancko reluctance type gage. This gage has been used in past nuclear tests with great success. For this reason it was used in key locations on the blast line to insure results.

2.2.6 Data Format (Data Presentation). All galvanometer recording was recorded on photo-sensitive paper driven at a speed of approximately 40 in/sec. The paper widths were 7 inches and 12 inches. The 12-inch paper had 18 data channels each, whereas the 7-inch paper had 8 data channels. Each record, in addition to the data channels, contained a timing channel, a TZ channel, and a reference trace. The electrical calibration steps were presented both immediately before time zero and postshot just before the recorders were shut down.

2.3 SELF RECORDING INSTRUMENTATION

The BRL mechanical self-recording gage, PHS (Pressure Hayden Standard), is a self-contained instrument employing a corrugated diaphragm sensor. The sensor used for project support was of the capsule type. It is constructed of two concentrically convoluted metallic diaphragms nestled one inside the other to provide minimum volume, welded together at the periphery, and silver soldered at the center to a mounting base. A light osmium-tipped spring stylus is soldered to the center of the free diaphragm. An increase in outside pressure entering through a small orifice in the base causes expansion of the diaphragms. The movement of the diaphragm is recorded by the stylus arm on a coated recording disk. Prior laboratory calibration using accurate dial gages was made to provide the relationship of pressure to deflection.

Recording of the capsule was made on an aluminized glass disk or a vapor honed stainless steel disk, depending upon the pressure range of the gage. The recording disks are centered on the gage turntable, with the coated side down, by a nylon cone and held in position by a neoprene-coated retainer. A chronometrically governed dc motor drives the turntable through a miniature coupling at a speed of 10 rpm.

The gages were initiated by a hard wire timing signal from EG&G or a cadmium sulfide photocell. Figures 2.14 and 2.15 show the photocell initiators.

A sensitive relay and power supply in the gage received the initiation pulse, electrically latched, and maintained continuity for the motor-power supply circuit. A star gear, cam operated cutoff switch, operated by the rotation of the turntable, opened the circuit controlling the number of revolutions that the turntable could make. A switch closure produced by an arming screw placed the gage in a ready state prior to evacuation of the area. Both the sensitive relay and power supply along with the motor power supply were mounted on a sheet metal can base and coupled to the base of the gage frame with an amphenol blue ribbon connector. See Figure 2.16 for a diagram of the gage circuit.

The frame making up the interior of the gage is a 4-inch steel H-channel, 8 inches long, welded to the center of a top plate 1/2 x 8 1/4-inch in diameter. The gage case is constructed of a 9-inch length of 5-inch-diameter pipe closed at the bottom with a 3-inch pipe cap welded to it. A flange, 1/2 x 8 1/4-inch in diameter, is welded to the top. In use, the gage is bolted to the top of the flange with a neoprene gasket, 1/8-inch thick, used to provide an air tight seal. Shown in Figures 2.17 to 2.20 are photographs of the gage.

Field mounting of the gages was accomplished by two methods. (1) The gage was buried with the flange flush with the ground surface. (2) The gage was screwed on a 3-inch-diameter pipe nipple, 8 inches in length, with a 1/4-inch steel plate, 12 inches in diameter, welded to the end. This unit was emplanted in the ground, with the gage flange flush with the ground surface. Sandbags were used to position the gages inside the several structures.

For the Project 27 stations a shock mounted gage system, PHS-IS (Pressure Hayden Motor Standard Shockmounted) was utilized. Figure 2.21 shows a schematic of the shockmounted unit. The mount case was cast of aluminum; the top plate was fabricated of stainless steel. It will be noted that rubber isolators were used in four equally spaced positions in the horizontal axis and one isolator was located between the gage and the top plate. Figures 2.22 to 2.24 illustrate further the design of this system. Installation in the field was made by screwing the gage and case on a 3-inch-diameter pipe, 4 feet long, embedded in concrete.

2.4 CALIBRATION

2.4.1 Electronic Transducers. Inherent nonlinearities, sensitivity to line length, and other impedance effects required that system calibrations be made after installation in the field.

Accelerometers were given static calibrations on a truck-mounted, Schaevitz spin-table before their installation. The spin-table contained a disk that was rotated at a speed determined accurately by an electric tachometer. The accelerometers were mounted on the disk with the sensitive direction parallel to the radius of the disk. Connections to the recorder cable were made through slip rings. An accurate knowledge of the distance of the accelerometer's center of mass from the center of the disk and the rotational velocity of the disk were used to find the radial acceleration produced in the sensing element. The disk velocity was varied to produce acceleration values of 20, 40, 60, 80, 100, and 120 percent of the predicted maximum. Spin-table acceleration values could be computed with an accuracy of ± 1 percent.

Displacement gages were calibrated with a dial micrometer as a standard. The micrometer measured the motion of the potentiometer wiper relative to its body support. The wiper was moved until its electrical center (the position giving an output voltage null) was found. The reading indicated by the micrometer was then taken as the zero reading, and from this point the body of the transducer was moved in a direction opposite to the actual displacement to produce calibration steps. Values, both positive and negative, of 20, 40, 60, 80, 100, 120, and 140 percent of the expected maximum were used.

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.

Strain gages, installed prior to arriving at the test site, were calibrated by simply shunting an arm of the strain bridge with precision resistors calculated to give simulated electrical signals of outputs representing 0, 20, 40, 60, 80, 100, and 120 percent of the maximum prediction.

2.4.2 Self Recording Gages. Calibration of all self-recording pressure sensors was made in the laboratory prior to installation in the gage. An arrangement identical to that in the gage was used in mounting the sensors in a calibration fixture. A 1/2-x 1-inch rectangular aluminized glass recording blank, located on the carriage section of the fixture, recorded the deflection of the sensor. Constant pressure was applied, controlled, and monitored by a commercially available control package and interchangeable dial gages (Figure 2.25), having an accuracy of 0.5 percent. A dead weight tester was used to pre-test the dial gages.

Disk-drive motor speeds were checked in the laboratory prior to field installation.

TABLE 2.1 Electronic Instrumentation for Project 3.3

Station Number	Arch No.	Gage Designation	Gage Range	Type Gage	Predicted Activation	Ground Range (ft)	Type Recorder
516.01	1	1 Pr 1	100 psia	CEC-4-312A	10 psi	920	CEC System D
		1 Pr 2	100 psia	"	12 psi	"	"
		1 Pr 3	100 psia	"	17 psi	"	"
		1 Pr 4	100 psia	"	25 psi	"	"
		1 Pr 5	100 psia	"	17 psi	"	"
		1 Acc 1	50g	Statham A-5	30g	"	"
		1 Acc 2	25g	Statham A-5	7g	"	"
		1 Acc 3	100g	Statham S-52	50g	"	"
		1 De 1	Model 108	Bourns	0.010 in.	"	"
		1 De 2	Model 156	Bourns	0.300 in.	"	"
		1 De 3	Model 108	Bourns	0.015 in.		
		1 Sg 1	15,000 to 20,000 µin/in.	Baldwin SR-4, A-5-IS6	600 µin/in.	"	"
		1 Sg 2	" "	"	200 "	"	"
		1 Sg 3	" "	"	150 "	"	"
		1 Sg 4	" "	"	140 "	"	"
		1 Sg 5	" "	"	140 "	"	"
		1 Sg 6	" "	"	200 "	"	"
		1 Sg 7	" "	"	260 "	"	"
		1 Sg 8	" "	"	100 "	"	"
		1 Sg 9	" "	"	400 "	"	"
		1 Sg 10	" "	"	600 "	"	"
		1 Sg 11	" "	"	200 "	"	"
		1 Sg 12	" "	"	600 "	"	"
		1 Sg 13	" "	"	240 "	"	"
516.02	2	2 Pr 1	100 psia	CEC-4-312"	10 psi	1160	"
		2 Acc 1	50g	Statham	20g	"	"
		2 De 1	Model 156	Bourns	0.20 in.	"	"
		2 Sg 1	15,000 to 20,000 µin/in.	Baldwin SR-4, A5-IS6	180 µin/in.	"	"
		2 Sg 2	" "	"	120 "	"	"
	3	3 Pr 1	100 psia	CEC-4-312A	10 psi	"	"
		3 Acc 1	50g	Statham A-3A	20g		
		3 De 1	Model 156	Bourns	0.18 in.	"	"
		3 Sg 1	15,000 to 20,000 µin/in.	Baldwin SR-4, A5-IS6	150 µin/in.	"	"
		3 Sg 2	" "	"	100 "	"	"

TABLE 2.1 (Continued)

Station Number	Arch No.	Gage Designation	Gage Range	Type Gage	Predicted Activation	Ground Range (ft)	Type Recorder
516.03	4	4 Sg 3	15,000 to 20,000 μin/in.	Baldwin SR-4, A5-IS6	----	1400	CEC System D
		4 Sg 4	" "	" "	----	"	"
		4 De 1	Model 156	Bourns	0.130 in.	"	"
		4 Sg 1	15,000 to 20,000 μin/in.	Baldwin SR-4, A5-IS6	120 μin/in.	"	"
		4 Sg 2	" "	" "	40 "	"	"
	5	5 Sg 1	15,000 to 20,000 μin/in.	Baldwin SR-4, A5-IS6	300 "	"	"
		5 Sg 2	" "	" "	120 "	"	"
		5 Sg 3	" "	" "	75 "	"	"
		5 Sg 4	" "	" "	70 "	"	"
		5 Sg 5	" "	" "	70 "	"	"
		5 Sg 6	" "	" "	100 "	"	"
		5 Sg 7	" "	" "	130 "	"	"
		5 Sg 8	" "	" "	50 "	"	"
		5 Sg 9	" "	" "	200 "	"	"
		5 Sg 10	" "	" "	300 "	"	"
		5 Sg 11	" "	" "	100 "	"	"
		5 Sg 12	" "	" "	300 "	"	"
		5 Sg 13	" "	" "	120 "	"	"
		5 Pr 1	100 Psia	CEC-4-312A	4 psi	"	"
		5 Pr 2	" "	"	5 psi	"	"
		5 Pr 3	" "	"	7 psi	"	"
		5 Pr 4	" "	"	10 psi	"	"
		5 Pr 5	" "	"	7 psi	"	"
		5 Acc 1	25g	Statham C-25	15g	"	"
		5 Acc 2	50g	Statham A-5	4g	"	"
		5 Acc 3	100g	Statham A-52	20g	"	"
		5 De 1	Model 108	Bourns	0.002 in.	"	"
		5 De 2	Model 156	Bourns	0.130 in.	"	"
		5 De 3	Model 108	Bourns	0.005 in.	"	"
516.04	6	6 Sg 1	15,000 to 20,000 μin/in.	Baldwin SR-4, A-5-IS6	75 μin/in.	1900	"
		6 Sg 2	" "	" "	50 "	"	"
		6 Pr 1	100 psia	CEC-4-312A	4 psi	"	"
		6 Acc 1	50g	Statham A-3A	10g	"	"
		6 De 1	Model 156	Bourns	0.09 in.	"	"

KEY:
Pr - Pressure
Acc - Acceleration
De - Deflection
Sg - Strain

TABLE 2.2 Self Recording Gage Support, Project 3.4

Project	Distance ft	Location	Type Gage	Initiation	Total
3.1	320	Free Field	PHS	PE	4
	365	Free Field			
	420	Free Field			
	615	Free Field			
3.2	325	Free Field	PHS	HW	4
	325	Inside Structure			
	680	Free Field			
	680	Inside Structure			
3.3	920	Free Field	PHS	HW	4
	1160	Free Field			
	1400	Free Field			
	1900	Free Field			
7.2	700	Free Field	PHS	PE	10
	700	Inside DOD			
	1200	Free Field			
	1200	Inside Tank			
	1550	Free Field			
	1550	Inside Tank			
	1800	Free Field			
	1800	Inside Tank			
	2100	Free Field			
	2100	Inside Tank			
27	175	Free Field	PHS-IS	HW	3
	216	Free Field			
	290	Free Field			

KEY: PHS - Pressure Hayden Standard
PHS-IS - Pressure Hayden Standard
Shock Mounted
PE - Photo Initiated
HW - Hardwire

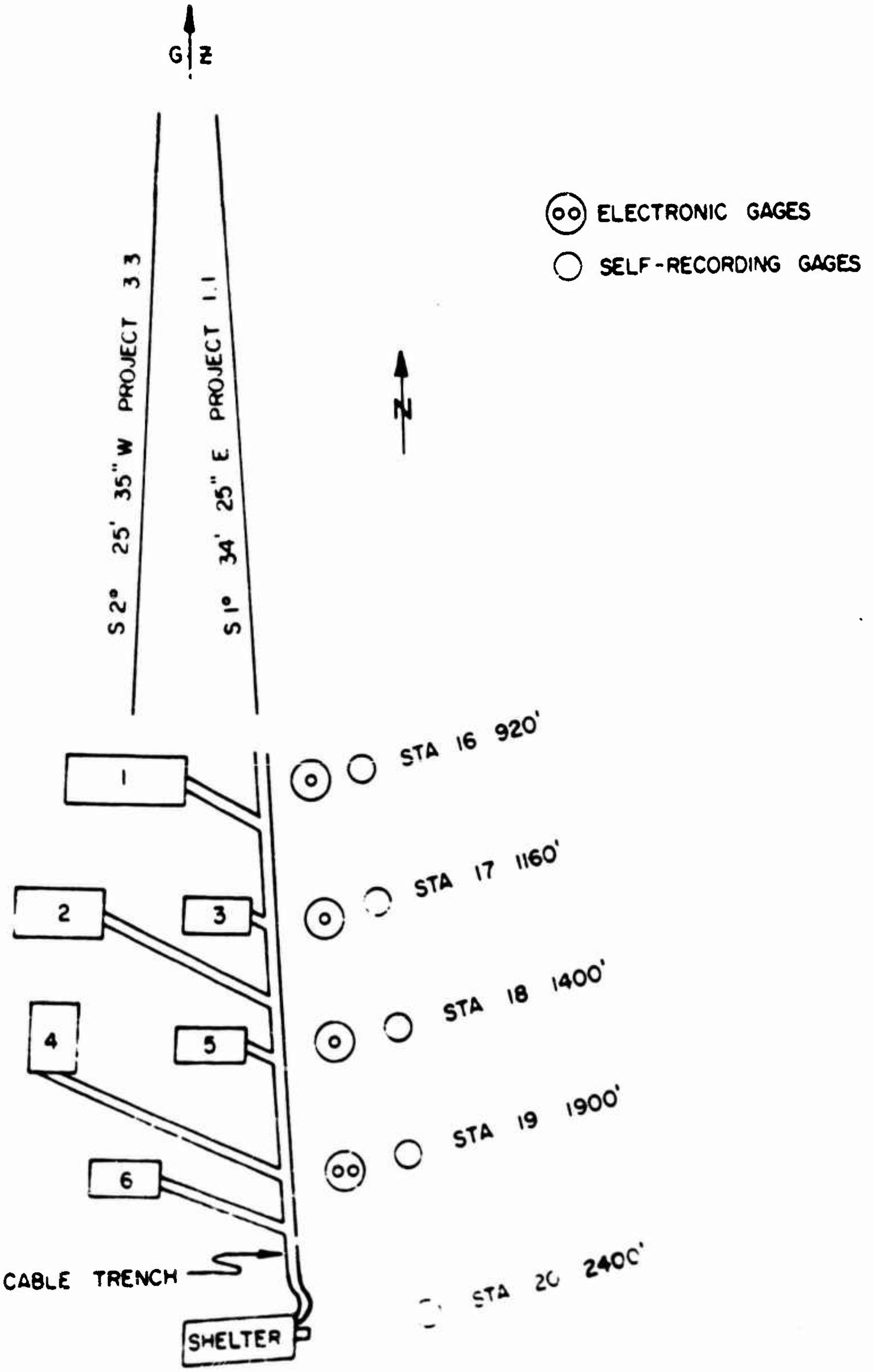


Figure 2.1 Location of Structures 3.3 and free-field recording instrumentation.

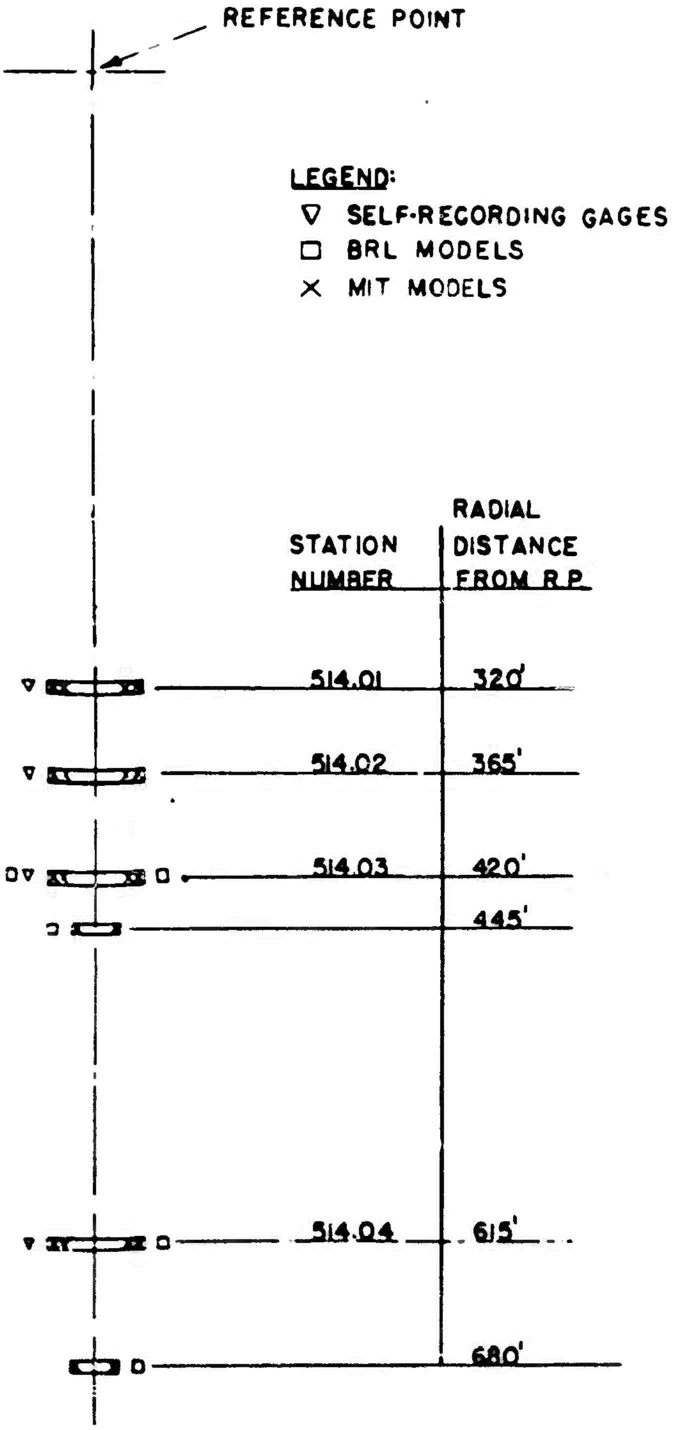
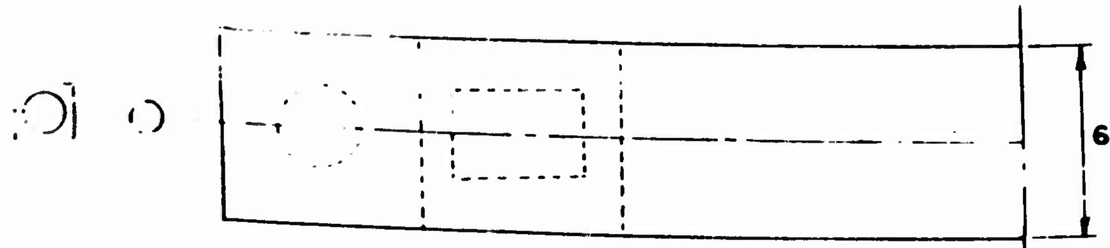
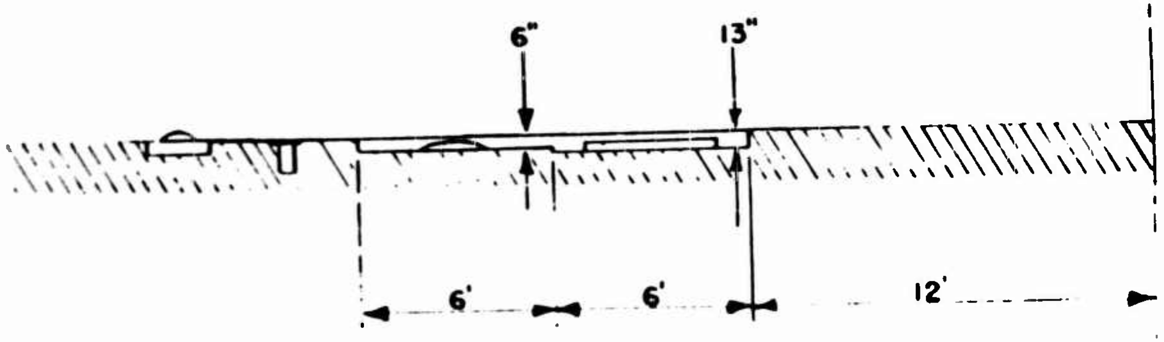


Figure 2.2 Layout of self-recording instrumentation for Project 3.1.



TOP VIEW



CROSS-SECTIONAL VIEW

Figure 2.3 Cross-sectional layout of Project 3.1 stations.

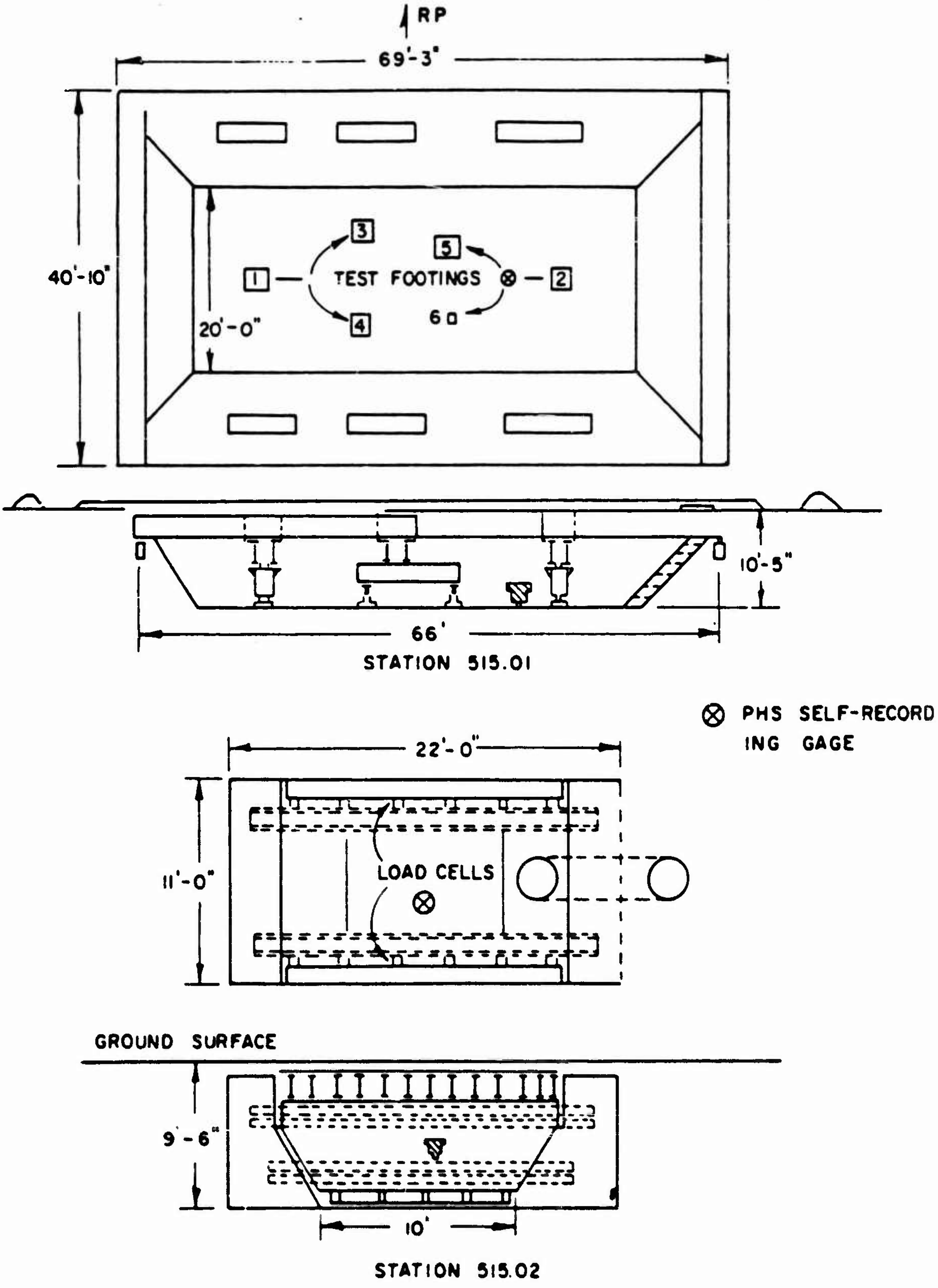


Figure 2.4 Location of self-recording gages, Project 3.2.

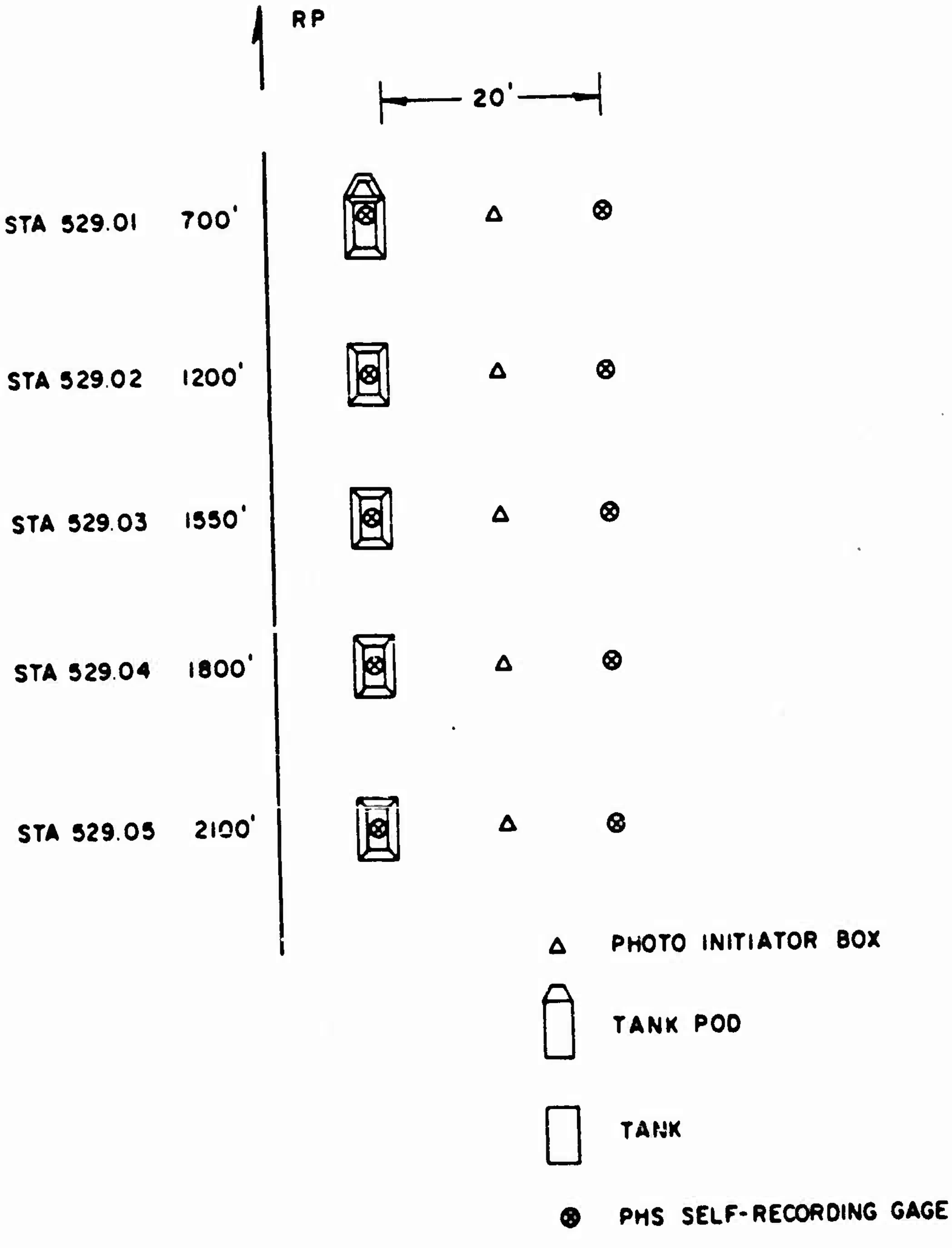


Figure 2.5 Location of gages, Project 7.2.

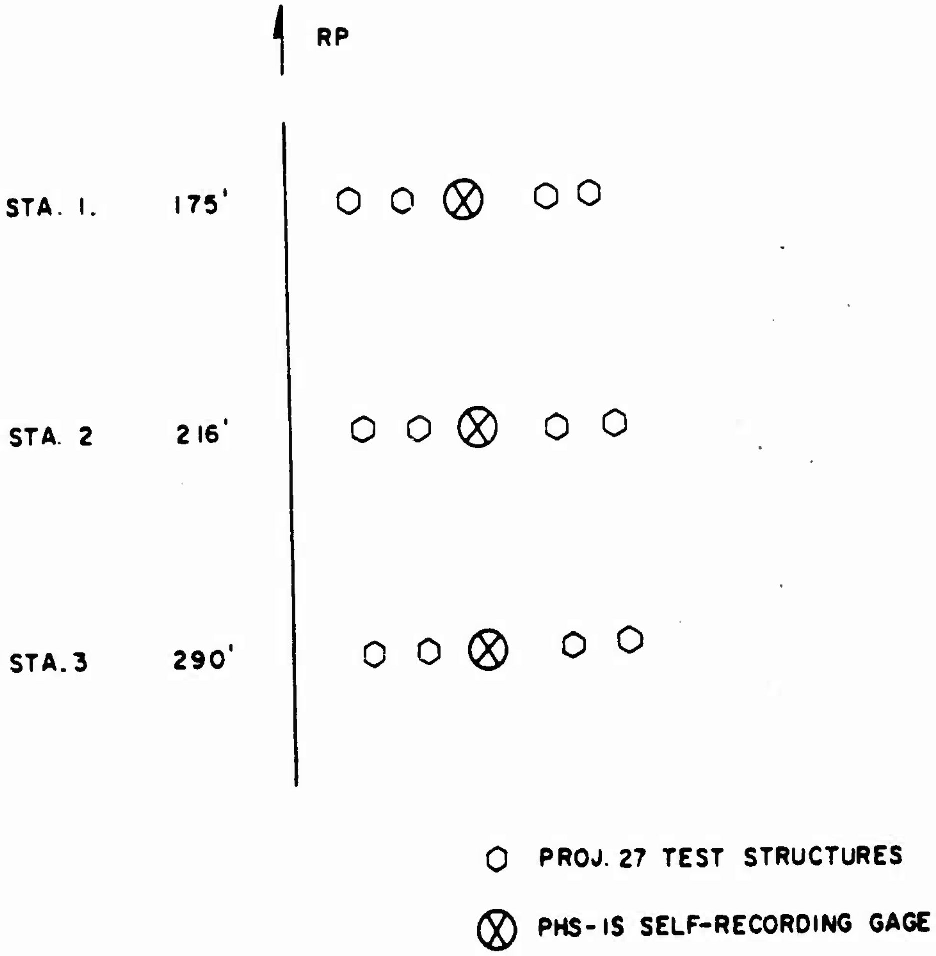


Figure 2.6 Location of gages, Project 27.

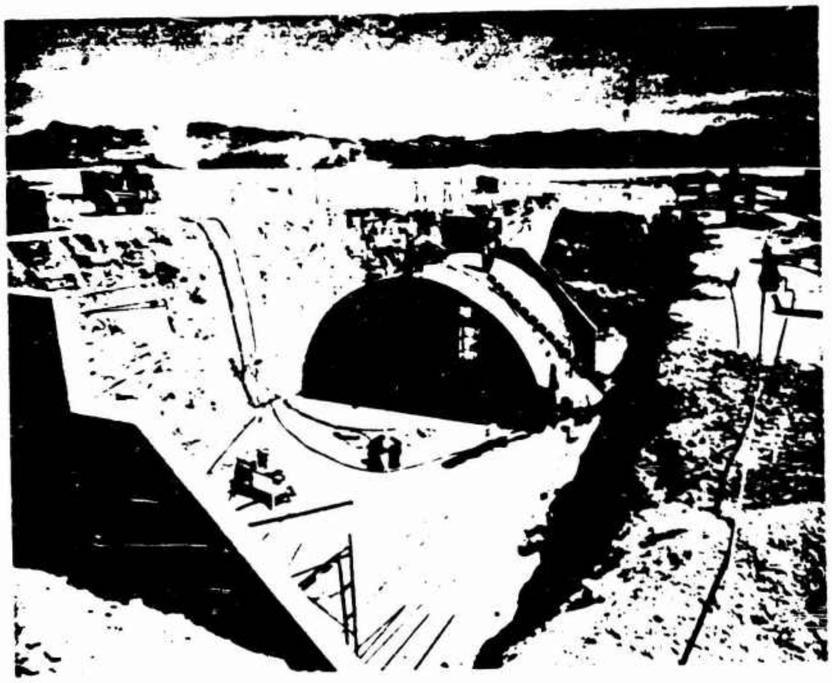


Figure 2.7 Shelter construction. (BRL photo)

Figure 2.8 Instrument benches. (DASA 1130-06-NTS-62)

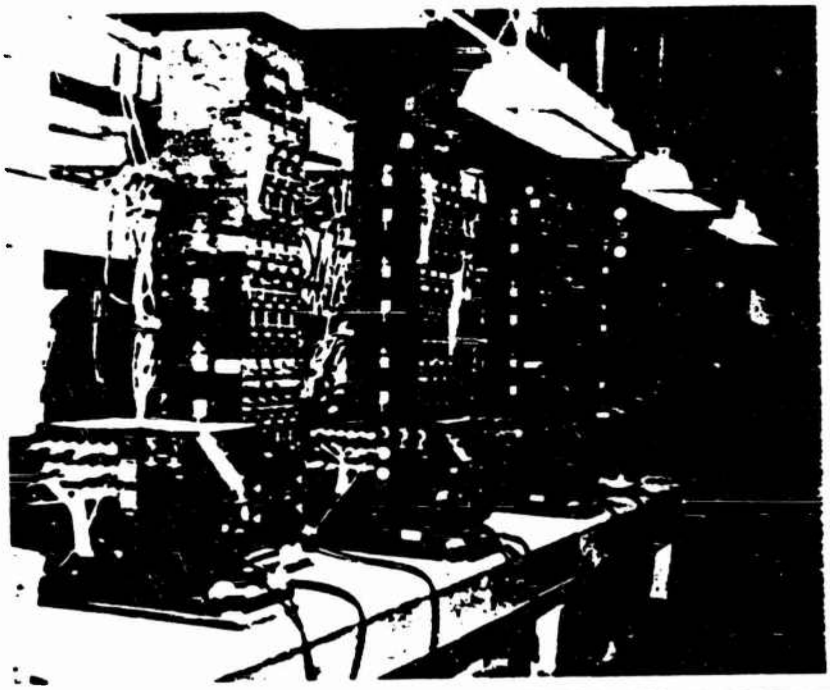


Figure 2.9 Electronic instruments. (DASA-555-08-NTS-62)

Figure 2.10 Power switching panel.
(DASA-555-03-NTS-62)

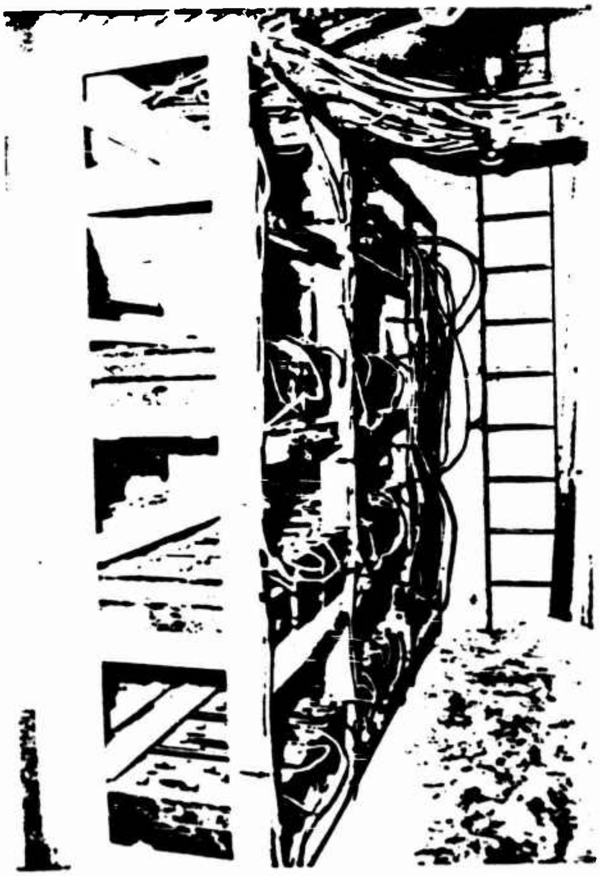


Figure 2.11 Battery installation.
(DASA-555-06-NTS-62)

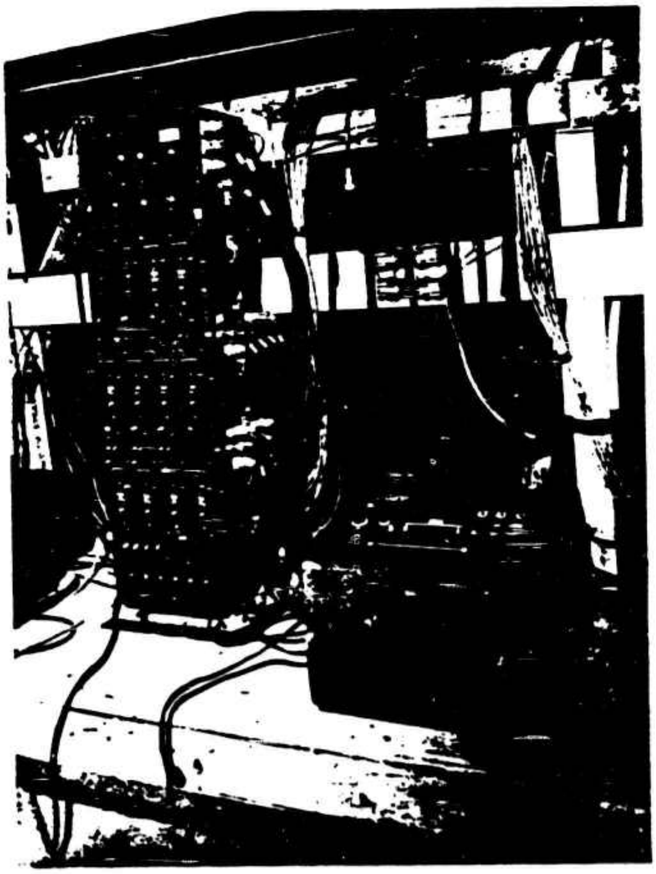


Figure 2.12 CEC 3-kc carrier system. (DASA-555-07-NTS-62)

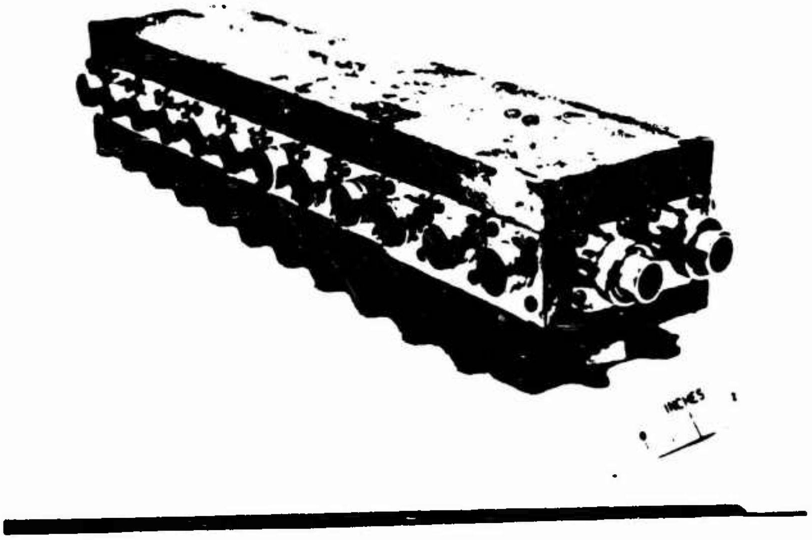


Figure 2.13 Transducer signal line grounding relay box. (DASA-535-07-NTS-62)

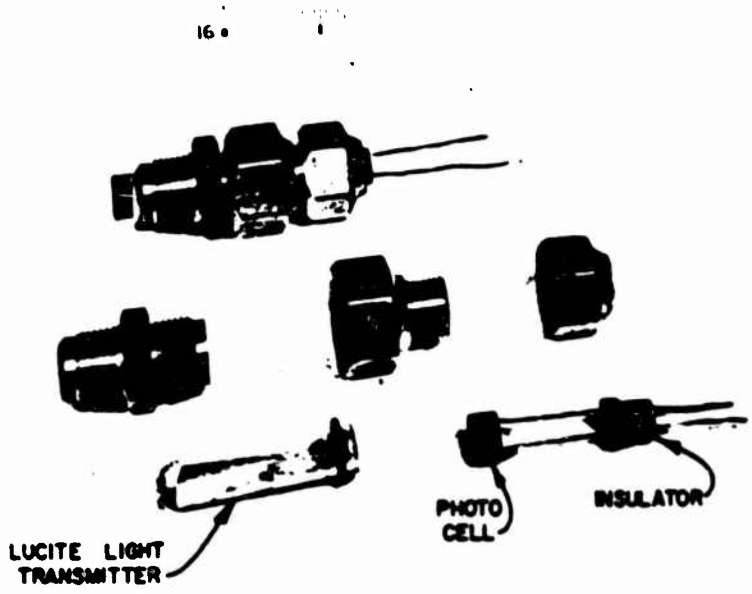


Figure 2.14 Cadmium sulfide photocell assembly, self-recording gages. (DASA-524-02-NTS-62)

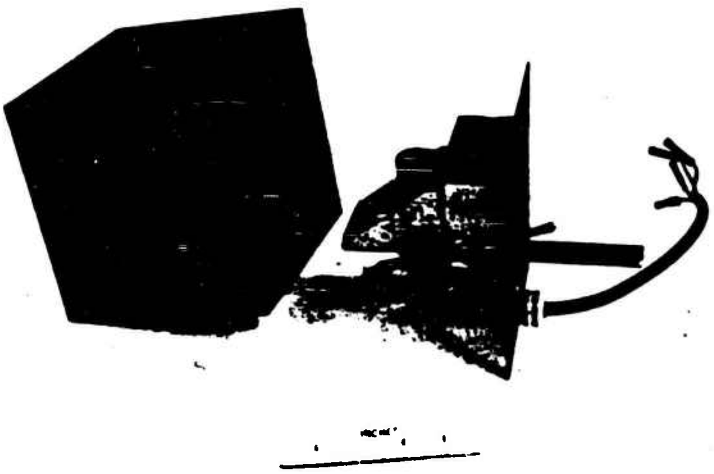


Figure 2.15 Cadmium sulfide photocell initiator package; self-recording gages. (DASA-524-14-NTS-62)

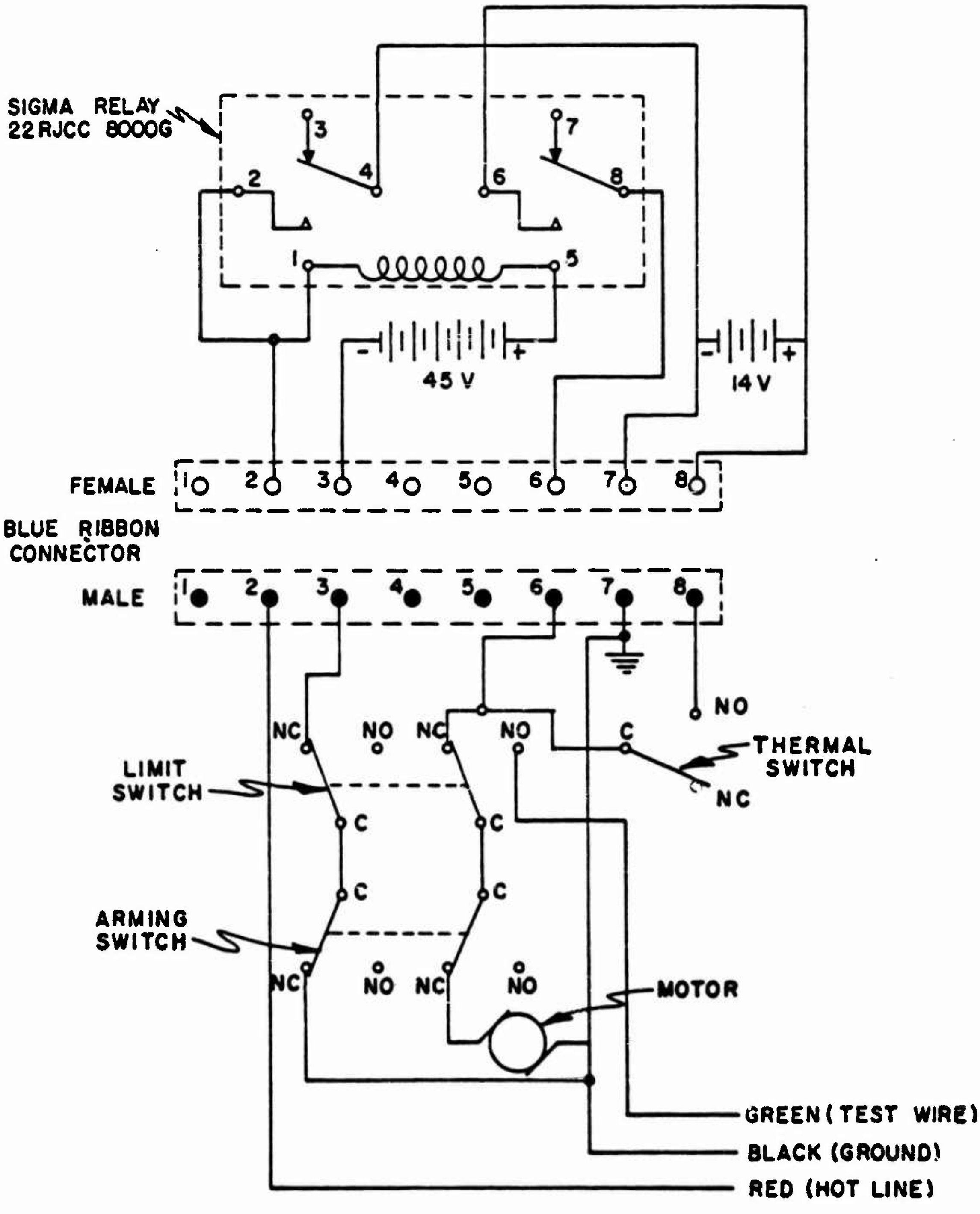


Figure 2.16 Schematic of gage circuit, PHS gage.

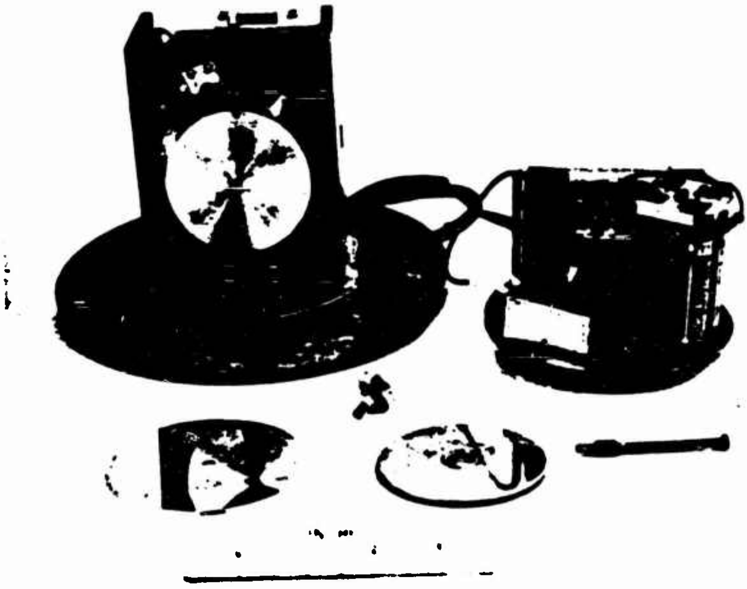


Figure 2.17 Exploded view, self-recording PHS gage. (DASA-524-03-NTS-62)

Figure 2.18 Rear view, self-recording PHS gage. (DASA-524-05-NTS-62)

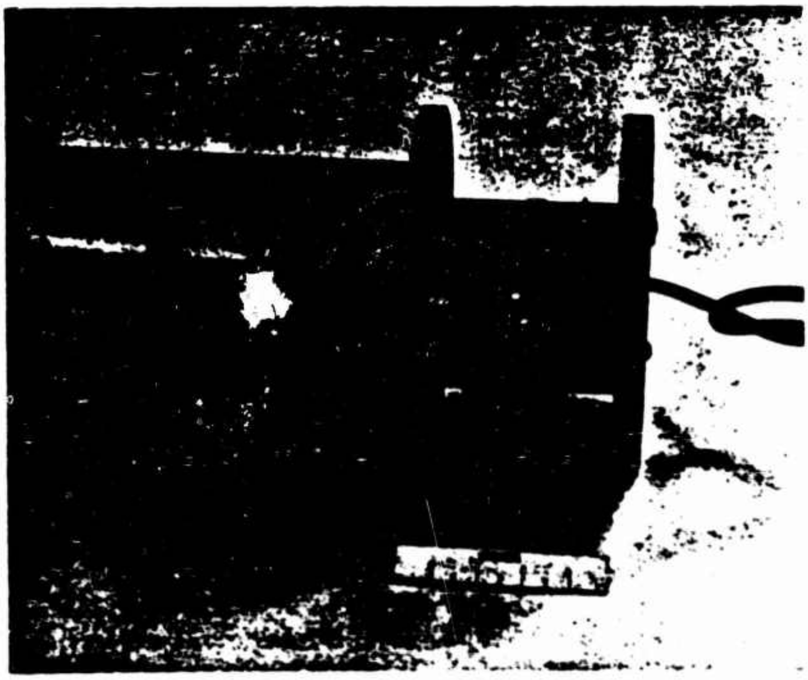


Figure 2.19 Semi-disassembled view, self-recording PHS gage. (DASA-524-01-NTS-62)

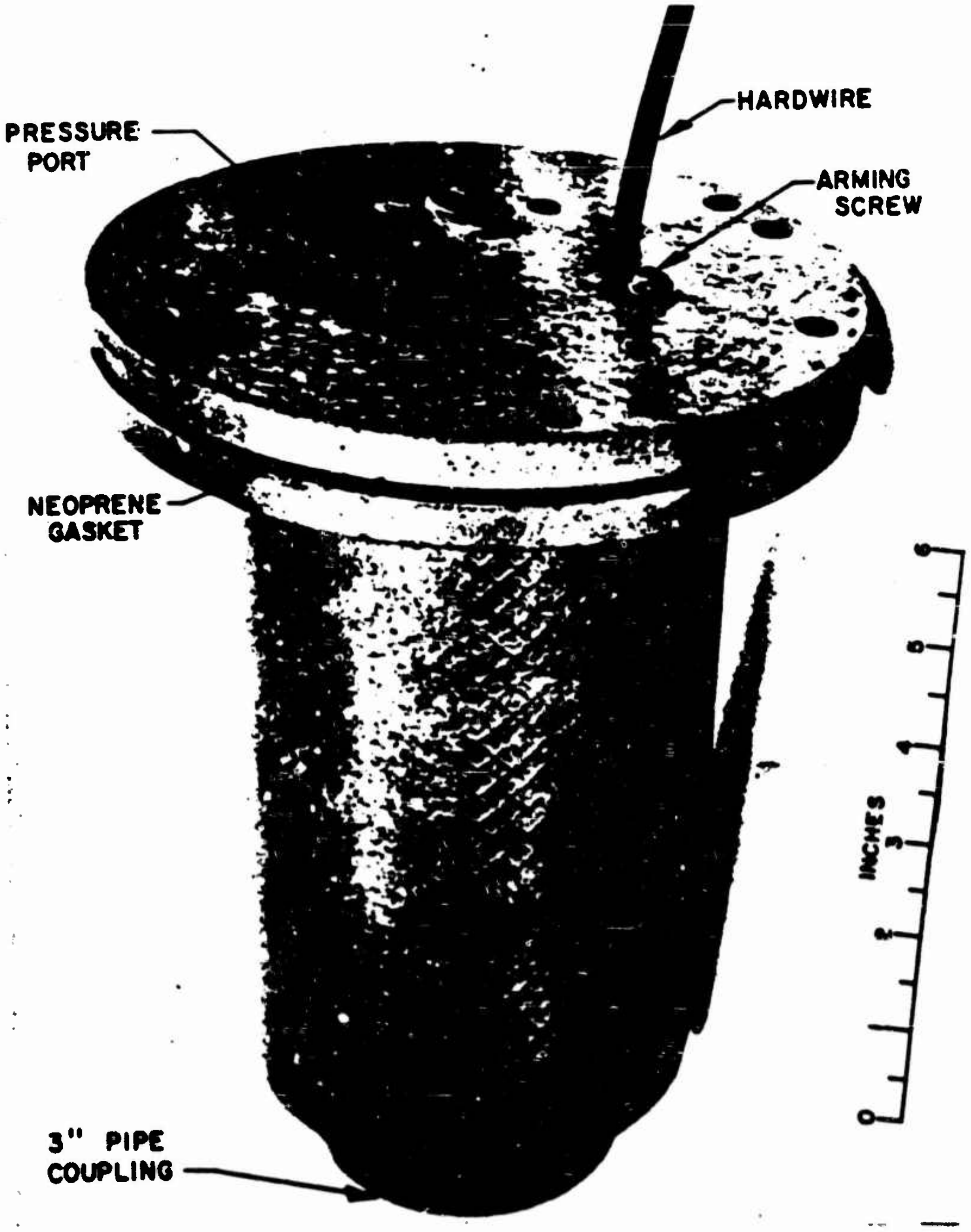


Figure 2.20 Assembled self-recording PHS gage. (DASA-524-04-NTS-62)

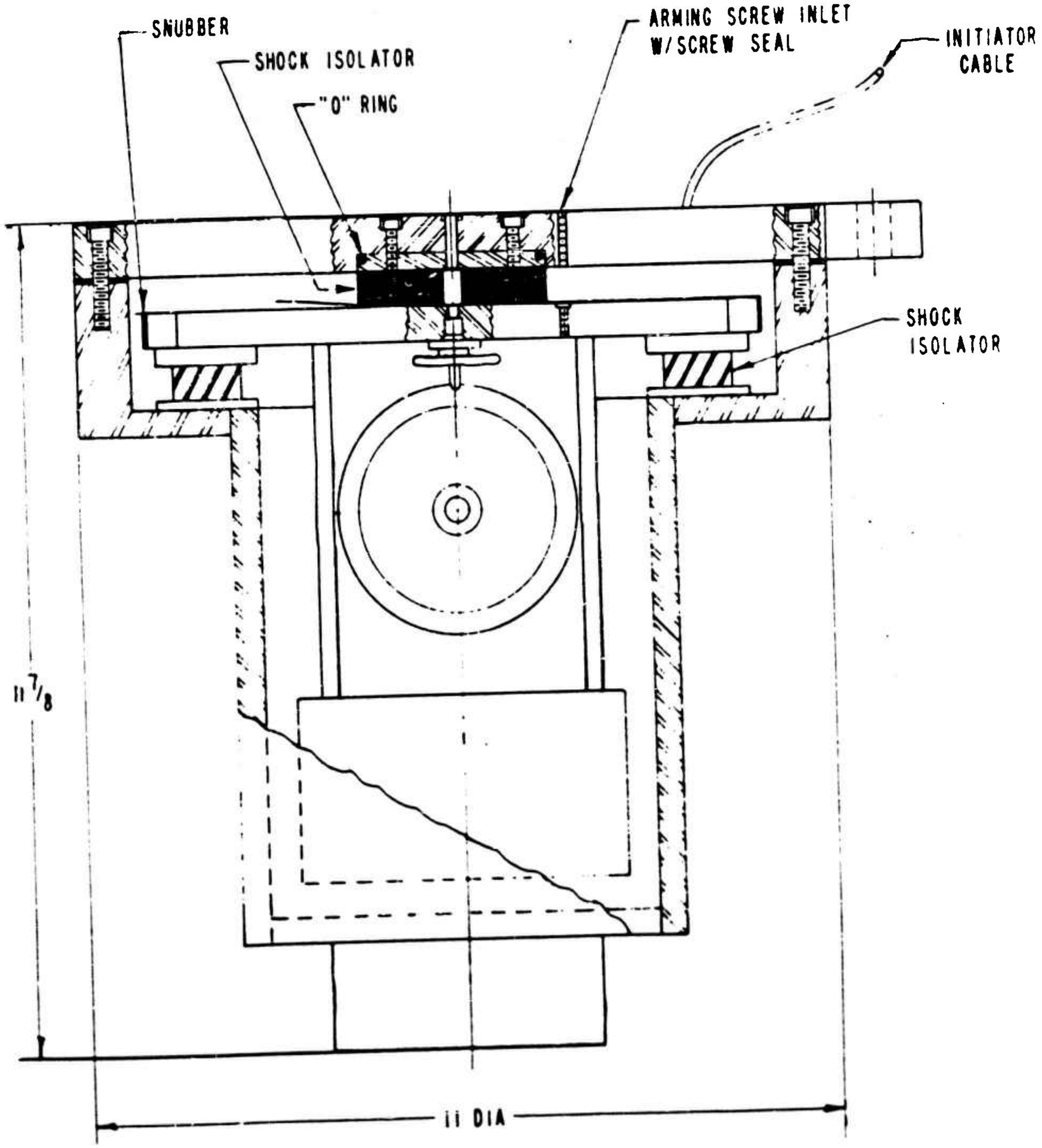


Figure 2.21 Schematic of self-recording PHS-IS gage.

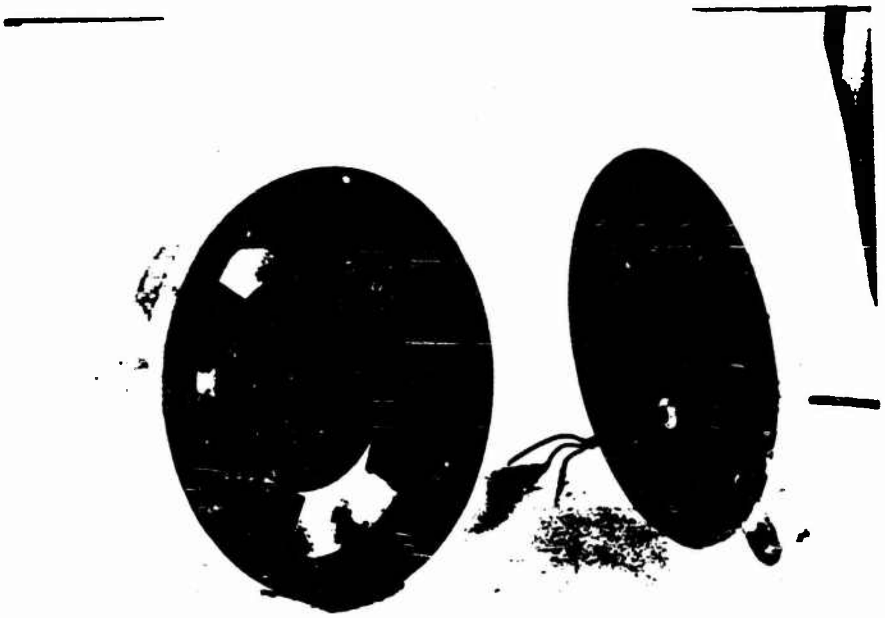


Figure 2.22 View of shock isolation system, self-recording PHS-IS gage. (DASA 524-19-NTS-62)

Figure 2.23 View of gage installed, shock isolation system, self-recording PHS-IS gage. (DASA-530-06-NTS-C2)

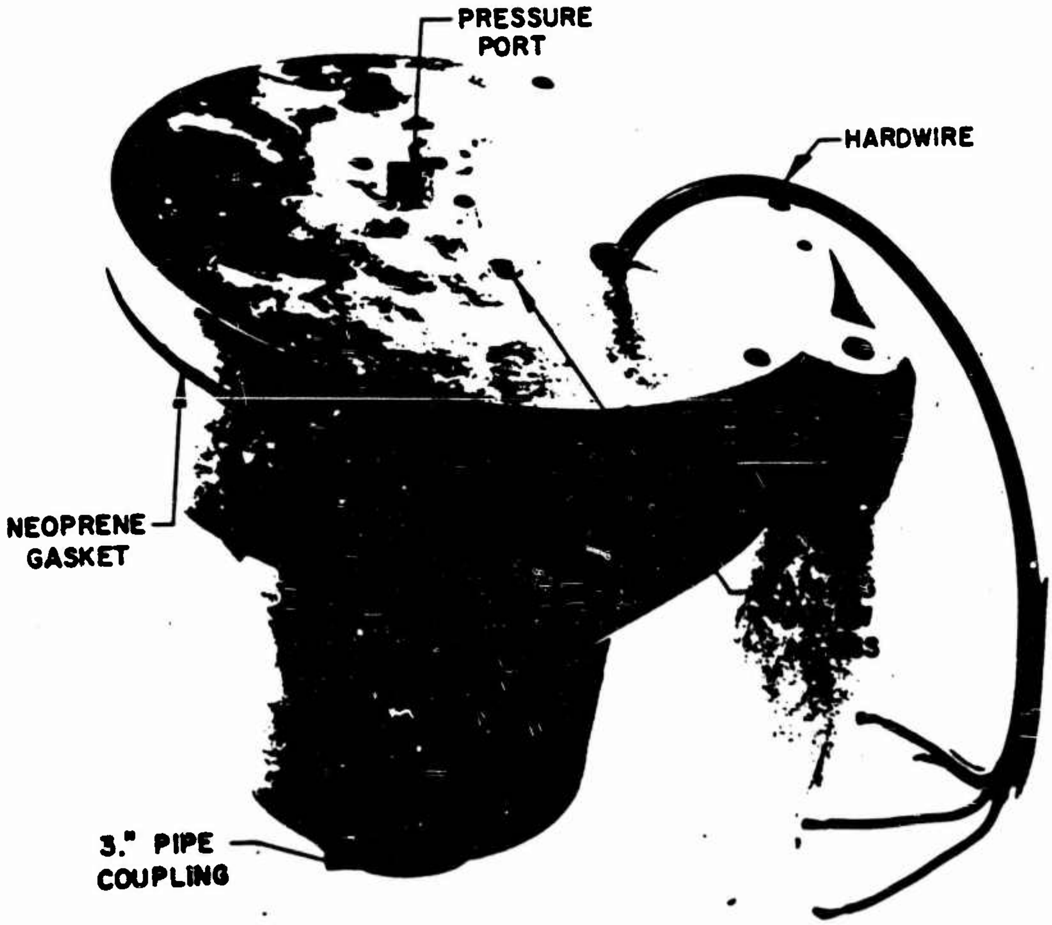


Figure 2.24 View of assembled PHS-IS gage. (DASA-524-13-NTS-62)

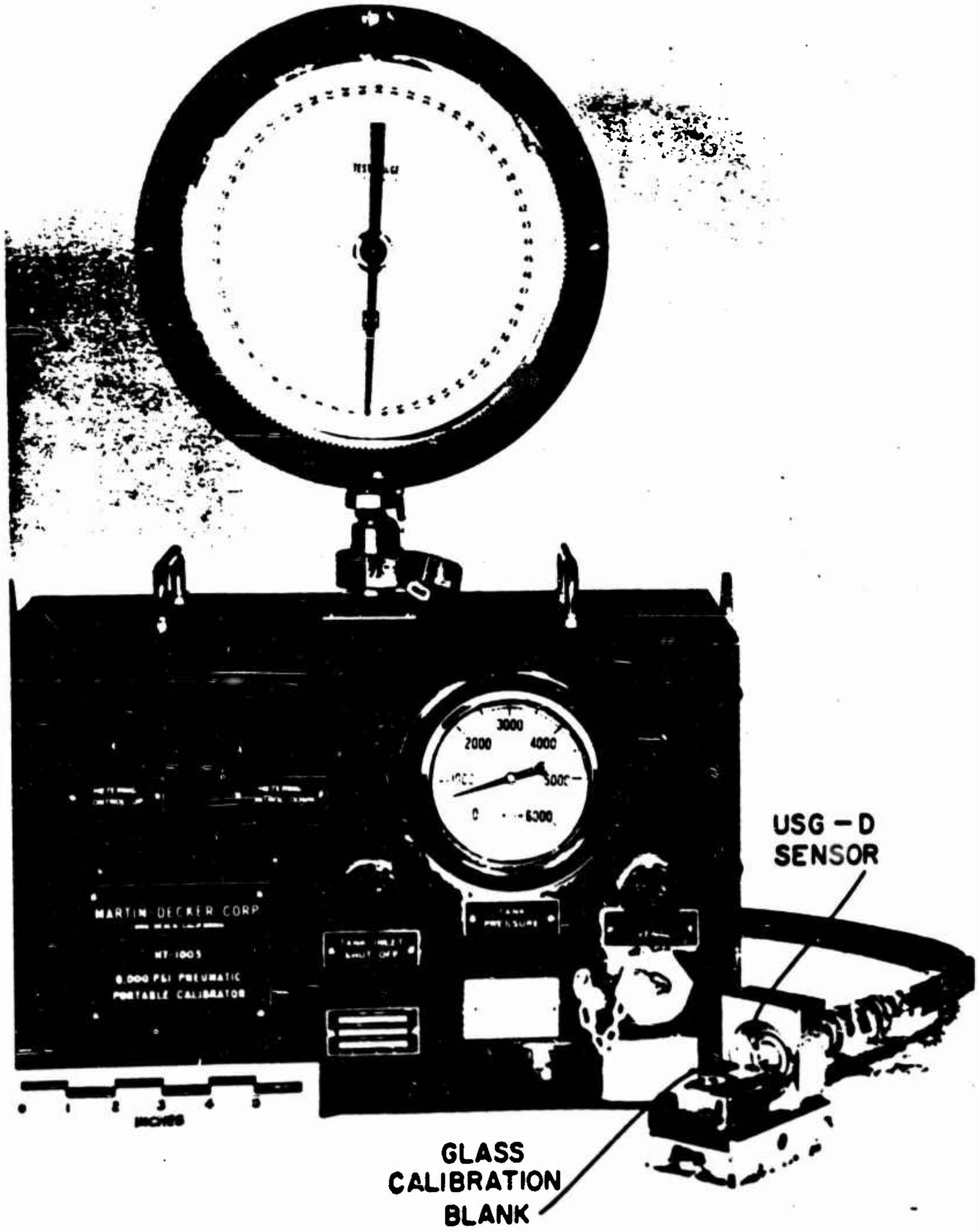


Figure 2.25 Pressure calibrator, self-recording gages. (DASA-530-00-NTS-62)

CHAPTER 3

RESULTS

3.1 DATA SUMMARY

The electronic instrumentation results for Project 3.3 are tabulated in Table 3.1. In general, the measurements made for Project 3.3 were successful. Forty-nine of the seventy-two channels recorded satisfactory data; sufficient back-up channels enabled accurate analysis of the structure response to be made. Four data channels, recorded with considerable noise, are considered useable. Three data channels were lost before the event for various reasons such as broken leads or defective transducers. Thirteen data channels of strain gage measurements were lost because of radiation pulse breakdown.

Detailed analysis and data presentation are presented in the Project 3.3 report. The self-recording instrumentation results are tabulated in Table 3.2. Data was obtained from all gages. Presented in Appendix B, Figures B.1 to B.6, are the pressure versus time plots from these records.

3.2 INSTRUMENTATION PERFORMANCE

3.2.1 Electronic. The recording systems and all the associated equipment performed satisfactory. The majority of the data channel losses were caused by electromagnetic pulse effects. A study of the electronic records indicates that the relay delay time was insufficient to allow the electromagnetic pulse to dissipate. Therefore, the channel losses cannot be contributed to malfunctioning of the protective devices but rather an underestimation of the time duration required for the grounding relay action to completely remove the electromagnetic pulse.

The logic units performed satisfactorily. A slight modification was required in component placement to prevent short circuiting the power relays.

The input circuitry performed satisfactorily; however, laboratory checks before arriving at the test site indicated that the difficulties would be less than existed during the test.

The successful performance of the equipment was due in part to the recording shelter. Its large size contributed to ease of installation, operation, and storage of field equipment. The large heat dissipation area of the metal shelter eliminated the need for air conditioning. The air pressurizing, filtering, and circulation greatly aided system operation and personnel comfort by preventing large quantities of dust from entering the shelter.

Power panel switching boards in the power room facilitated the usual problem of power handling. These panels enabled instrument operators to conveniently power any system from any battery supply or change any battery supply with any charging system.

3.2.2 Self Recording

In general, the self-recording gages performed well. All gages used for projects 3.2, 3.3, and 7.2 functioned and yielded usable data. Gages utilized for Project 3.1 were disturbed by environmental effects. Those at Stations 514.02 and 514.03 were affected by acceleration resulting in a shift in the recording disk and a resultant shift in the pressure trace; the gage at Station 514.01 revealed excessive backlash, making impossible an accurate reading of the positive duration. The cadmium sulfide photocell initiators of both varieties performed as programmed. The gages used for Project 27 operated in a satisfactory manner.

Appropriate remarks regarding the quality of the records are presented in Table 3.2.

TABLE 3.1 Electronic Instrumentation Results

Structure	Recorder	Channel	Transducer	Record Quality		
				Good	Poor	NG
Arch I	4	1	0 Pr 1	X		
	1	3	1 Sg 1			X
	1	6	2	X		
	1	8	3	X		
	1	10	4	X		
	1	14	5			X
	1	16	6			X
	1	19	7	X		
	1	21	8	X		
	1	25	9	X		
	1	27	10	X		
	1	29	11			X
	1	31	12			X
	1	33	13			X
	3	3	1 Pr 1			X
	3	10	2			X
	3	16	3	X		
	3	21	4	X		
	3	27	5	X		
	4	7	1 De 1		X	
	4	11	2	X		
	4	15	3	X		
	2	12	1 Acc 1	X		
	2	18	2	X		
	2	23	3			X
Arch II	5	1	0 Pr 2	X		
	3	6	2 Sg 1			X
	3	12	2 Sg 2	X		
	6	13	2 De 1		X	
	4	3	2 Pr 1			X
	5	11	2 Acc 1	X		
Arch III	3	18	3 Sg 1	X		
	3	23	2	X		
	4	13	3 De 1	X		
	5	6	3 Pr 1			X
	6	9	3 Acc 1	X		

Key to Transducer Designation

Pr = Electronic Pressure Transducer
Sg = Strain Patch Transducer
De = Deflection
Acc = Acceleration
Prefix 0 = Surface
Prefix other than 0 = Arch Number
Suffix = Transducer location on structure

TABLE 3.1 (Continued)

Structure	Recorder	Channel	Transducer	Record Quality		
				Good	Poor	NG
Arch IV	6	1	0 Pr 4	X		
	6	3	4 Sg 1			X
	6	7	2	X		
	6	11	3	X		
	6	15	4	X		
	4	5	4 De 1	X		
Arch VI	3	1	0 Pr 6	X		
	3	29	6 Sg 1	X		
	3	33	2	X		
	5	15	6 De 1	X		
	6	5	6 Pr 1	X		
	4	9	6 Acc 1	X		
Arch V	2	3	5 Sg 1			X
	2	6	2			X
	2	8	3	X		
	2	10	4	X		
	2	14	5			X
	2	16	6	X		
	2	19	7			X
	2	21	8			X
	2	25	9	X		
	2	27	10	X		
	2	29	11		X	
	2	31	12	X		
	2	33	13	X		
	5	3	5 De 1	X		
	5	9	2	X		
	5	13	3	X		
	3	8	5 Pr 1			X
	3	14	2	X		
	3	19	3	X		
	3	25	5 Pr 4	X		
	3	31	5	X		
	1	12	5 Acc 1	X		
	1	18	2	X		
	1	23	3		X	

(page 51 deleted)

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The instrumentation utilized to obtain data in support of the requesting agencies was adequate to accomplish the objective. Modifications to the instrumentation procedure to gain improved results are desired.

It is to be noted that a precursor waveform was recorded by gages on the Project 1.1 blast line at the 380-, 520-, and 680-foot stations although classical type waveforms were recorded at the 325-foot station immediately preceding and at the 830-foot station immediately following. Although distorted waveshapes were recorded at the corresponding distances on the Project 3.2 and 7.2 line, it is concluded that the environmental effects sustained by the gages preclude definite ascertainment of a precursor at these positions unless a symmetrical wave is assumed.

4.2 RECOMMENDATIONS

A detailed postshot inspection of transducers and their related mounts and cables indicated improvements in techniques and equipment are necessary before satisfactory measurements are assured. Upon inspection, it was found that all buried signal cables were in satisfactory condition. Spark-gaps did survive in most instances; however, their points were burned or welded together.

Close-in transducers and dynamic mounts suffered severe damage. A detailed listing of damage and recommendations for instrumentation improvement are given in Reference 1.

A review of electromagnetic pulse deleterious effects indicates that although the signal lines were not damaged and the effects were minimized by spark-gaps and signal grounding techniques, the pulse effects will have to be more totally removed by intensive shielding or essential elimination of signal cables of extensive length. The time delay requirement for effective grounding of signal cables is too long to remove sufficient cable charge before activation arrives at the close-in station transducers. It is recommended that all instrumentation including the transducers be enclosed in triple shielding to eliminate the electromagnetic effects. Radiation and thermal effects on the electronic recorders may be diminished as desired by regulating the burial depth.

APPENDIX A

SUPPLEMENTAL ELECTRONIC INSTRUMENTATION REQUIREMENTS FOR FIELD TESTS

Effects measurements of nuclear or high-explosive field tests, when associated with certain recording equipment, inherently require long transducer cables and a variety of transducers with various electrical characteristics. These conditions create a requirement for a broad range of control for electrically phasing and balancing transducer signals during calibration. BRL designed and obtained equipment to enhance the Consolidated Electrodynamics Corporation (CEC) System D for field use. This equipment consists of coupling units and logic units. The coupling units broaden the phasing and balancing ranges of the systems and provide other features as discussed below. The logic units provide the systems power and control switching, both manually and remotely. Form factors of the coupling units and the logic units match System D.

A.1 COUPLING UNITS

A.1.1 Functions

The functions of the coupling units are described as follows:

(a) Provides for local and remote control of electrical calibration steps.

(b) Provides auxiliary transducer zero balance controls.

(c) Provides controls for phase, and thus deflection, reversal of transducer, and electrical calibration signals.

(d) Provides optional oscillator power supply isolation from the transducers.

(e) Provides vernier signal attenuator control.

(f) Provides solderless mounting for phase altering and shunt calibrating elements.

(g) Provides carrier and signal monitoring points.

A. 1. 2 Description. Stacking, size, style, and finish of the coupling unit cases are similar to that of the CEC systems as may be seen in Figures A.1, A. 2. Width and depth of the coupling unit cases are equal to those of the original system, while the height is 4-1/2 inches. The individual coupling units are sliding drawers, one per channel. When the coupling unit drawer, directly below its corresponding amplifier, is in the open position, all of the channel controls are readily accessible and in close proximity to the operator. When the drawer is closed, its controls are enclosed to prevent accidental movement.

A. 1. 3 Controls and Binding Post. (See Figures A. 3 and A. 4)

(a) Zero Bal. , Phase potentiometer.

Balances the resistive component in any residual transducer signal.

(b) Zero Bal. , Ampl. potentiometer.

Balances the resistive component in any residual transducer signal.

(c) Balance binding posts.

Mounting for capacitor and resistor which control sensitivity of zero balance potentiometers.

(d) Attenuator potentiometer.

Provides vernier control of deflection sensitivity.

(e) Carrier ± switch.

Reverses phase of the carrier, causing deflection polarity reversal.

(f) Cal 50 percent - 0 - 100 percent switch.

Manual control for two electrical calibration steps

(g) Cal ± switch.

Reverses polarity of electrical calibration signal.

(h) 50 percent and 100 percent binding posts.

Mounting for electrical calibration shunts.

(i) Isolate , short switch.

Provides carrier isolation between channels so that any carrier short external to the recording system affects only one channel.

(j) 2-4 Arms switch

Inserts two dummy arms for use with 2-arm transducer bridges.

(k) Signal binding posts.

Monitoring points for suppressed carrier signal, and mounting for phase shifting elements.

(l) Carrier Monitor jacks (one set per coupling unit case).

A. 1. 4 Circuit Discussion. For reference during the circuit theory discussion see the System D coupling unit schematic, Figure A. 5. Switch S-1, the Isolate - Short switch serves to short resistors R-1 and R-2, which are in series with the transducer excitation lines. In the Isolate position a carrier short in the transducer or its cable will have a negligible change in the excitation voltage of other transducers on the same oscillator power supply. Of course, the transducer excitation is reduced by about R/120+R where R is the input resistance of the transducer bridge. The reduction factor becomes more complex with use of variable reluctance bridges, but in this case the transducer sensitivity is usually so high as to make the excitation loss trivial. Potentiometer R-5 is a series attenuator which provides convenient vernier control between any pair of adjacent amplifier attenuator settings. R-5 also serves to attenuate the high output of variable reluctance transducers to a level the System D can tolerate. R-5 requires the use of R-3 and R-4, which make up a pair of dummy bridge arms. The dummy arms are switched in and out of the circuit by S-5, the 2-4 arm selector switch. System D's 2-4 arm switch is always left in the 4 position. Potentiometers R-6 and R-7 are auxiliary amplitude and phase zero-balance controls which may be used with the amplifier's controls to provide a wider range of zero balancing voltages. In most instances, R-6 and R-7 will also provide a more precise zero balance. The three balance binding posts hold the resistor and/or capacitor, which determine the sensitivity and range of R-6 and R-7. Switch S-3, the Carrier ± switch, reverses the carrier phase on the transducer and the coupling unit, which reverses the direction of galvanometer output deflection from both the transducer and the electrical calibration circuit. Switch S-4, the Cal ± switch, reverses the phase of the electrical calibration signal only, by switching one side of the shunt calibrating elements to one or the other side of the carrier line. The three Cal Resistor binding posts serve to mount the shunt calibrating elements which may be resistors; capacitors, inductors, or some combination thereof. RY-1 and RY-2 are calibration relays. Since RY-1 is normally closed, RY-2, when actuated, will shunt the 100-percent calibrating element across one arm of the transducer bridge. When RY-1 is also actuated, the 50-percent element is placed in series with the 100-percent element, shunting the bridge arm. If the two elements have equal impedances, the two deflections produced usually will have a 2-to-1 ratio, except in rare cases when phase relationships cause nonlinearity. The calibration relays may be actuated by switch S-2, the 50 percent - 0 - 100 percent Cal switch, which causes only one channel to calibrate, or from the logic unit, which causes all channels to calibrate. Diodes D-1 and D-2 prevent S-2 from effecting calibration relays in other coupling units. C-1 with R-8 and C-2 with R-9 are time delay networks for RY-1 and RY-2, respectively. In any coupling unit case of four channels, C-1 and C-2 each will have the following values left to right: 0 mfd, 10 mfd, 20 mfd, and 30 mfd. This separates the adjacent channel calibration steps on the oscillograph record such that they are easily identified. All connections to the coupling unit are made through connector J-1.

A. 2 LOGIC UNITS

The logic units are described as follows:

A. 2. 1 Description

Stacking, size, style, and finish (see Figures A.6, A.7, and A.8) of the logic unit are similar to the System D . Width and depth are equal to the CEC equipment, and the over-all height is 7 inches.

A.2.2 Functions

The logic units primary function is to accept remote field timing relay closure commands and from them cycle the systems D recorders through a data gathering sequence. The Command and responses are as follows:

Command Closures	Responses
- 30 minute - 15 minute (backup)	Turn on all warmup power to recording system
- 10 second - 5 second (backup)	Start Oscillograph Charts 50 percent calibration step on 100 percent calibration step on Calibration off Data recording (Shot) 50 percent calibration step on 100 percent calibration step on Calibration off Stop Oscillograph Charts Turn off all warmup power to recording system

A.2.3 Operation

Each calibration step is about 1 second long, and the data run between preshot and postshot calibrations lasts about 20-2/3 seconds. Before the first paper-start closure is received, the warm-up power may be turned off simply by opening both the -30 minute and -15 minute closures. Now warmup will reoccur when either or both the -30 minute and -15 minute closures operate. Recycling the warmup can be done as often as needed within the limits of the system power supplies. After paper-start, the remote lines lose control, and the system will complete a sequence and cannot be recycled remotely. Of course, the logic unit can be recycled after the local reset button is held down for four seconds. Switches on the front panel provide complete local control.

The logic unit will respond to the warmup command with either a 115-v ac ± 15 percent, 60-cps line, or 24 to 28-v dc power source; however, it will not respond to the paper-start command until it is supplied 115-v ac. Therefore, if batteries are used with 24-v dc, to 115-v ac converters, then a converter output must be fed back into the logic unit to operate the timing motors, the internal dc power supply, and the cooling blower motor. Each logic unit will serve up to twelve channels of amplifiers, plus two oscillographs (ac or dc, 3-½ to 12 inches). Its power control circuits are two 24-v dc, common negative, B+ isolated, rated at 60 amps each and two 115-v ac circuits, isolated, one rated at 20 amps and the other at 15 amps. Relay contacts which start the oscillograph paper are rated at 2 amps. The internal dc power supply provides power for the coupling unit calibration relays, logic unit switching, and indicator lamps. An adjustable timer (No. 1) will, if switched into the circuit, generate a time interval from 2 sec to 2 minutes between the remote start command and the actual paper start. This is for use where long arrival times are involved.

A.2.4 Circuit Discussion

For reference during the circuit theory discussion see the logic unit schematic, Figure A.9, and the timer No. 2 switch program, Figure A.10. To better exhibit how the logic unit integrates with, and controls the recording systems, assume the lay-out shown in block diagram in Figure A.11. Interconnecting cable schematics are shown in Figures A.12 thru A.18. Assume all switches and relays are in the normal (reset) position as shown except switch S-1, the main ac power switch; assume it is closed. Since RY-2 is open, the converters cannot be running so there is no ac power. The only power being consumed is by the two green 28-v IN indicator lamps and the blue reset lamp. This is a total of less than 3.5 watts; however, the lamps may be removed if the batteries must remain for extended periods without being charged. Warmup may be initiated by throwing the warmup switch S-2 up. A similar response results from shorting pin 1 to 2 (usually the -30 minute short) or pin 4 to 5 (usually the -15 minute short) of the remote control connector J-1. A resistance of 150 ohms or less in the remote control cable will not affect the logic unit operation. RY-1 pulls in and connects RY-3's latching coil to the start line and closes RY-2, which applies 28 volts to J-2 and J-3, which start both converters, and Oscillograph 1 begins to warm up. The converters supply ac warmup power to the Systems, Oscillograph 2, and P-3 of the logic unit. Since S-1 is closed, the AC-1 indicator lamp, cooling blower motor, and dc power supply are energized. If the warmup closure is opened the system will revert to the off condition until another closure is given. Assuming the system to be in the warmup condition, at say -10 seconds, Pins 1 and 3 of J-1 are shorted; this may be backed up at say -5 seconds by shorting pins 4 and 6, and has the same effect as throwing the momentary Start switch S-3. The start command closes latching relay RY-3; contacts RY 3-2 turn off the blue Reset lamp and lock RY-1 in the pulled in position, which similarly holds RY-2 closed, independent of the warmup closure. Since RY-3 is a latching relay, it remains in the latched position independent of the start closure. The remote control lines are now locked out. Contacts RY 3-1 energize timer motor TM-1 through S-6, the Timer 1 in-out switch. Timer 1 starts, runs out its preset interval (2 sec. to 2 min.), and then closes and holds TS1-1 which energizes timer motor TM-2. If S-6 is in the Out position RY 3-1 will start TM-2 immediately. Now referring to the Timer 2 switch program in Figure A.10, starting at time zero which is -10 seconds by the remote control timing, it is seen that switches TS2-1, TS2-2, and TS2-3 close almost simultaneously in about 1/3 second. TS2-1 and TS2-2 actuate the coupling unit's calibration relays to produce a 50-percent

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calibration step on all channels by applying +33 volts from the logic unit power supply to Pins 1 and 2 of J-7, J-8, and J-9. Both the red calibration indicator lamps are energized. TS2-3 energizes relays RY-4 and RY-5, which start the paper drive motors in both oscillographs so the 50-percent calibration step is recorded on the charts. TS2-1 opens after one second, which removes +33 volts from Pins 2 of J-7, J-8, and J-9, which releases one relay in each coupling unit to produce the 100-percent calibration steps. One of the red calibration indicator lamps goes off, leaving the 100-percent indicator on. TS2-2 opens after one second of 100-percent step, the recorder traces return to their zero baselines, and the 100-percent indicator goes off. TS2-5 closed at one second after TM-2 started, but this has no immediate effect on the system; thus, at 2-1/3 seconds after TM-2 is started, the recorders are calibrated and ready to record the transducer data. This condition persists for 20-2/3 seconds, when an identical calibration sequence begins. Twenty-five seconds after TM-2 is started, the traces return to zero baseline again. One-third second later TS2-3 opens, which opens RY-4 and RY-5, stopping the oscillograph charts. In another 1-2/3 seconds TS2-4 opens the RY-1 coil circuit, which de-energizes RY-2, which turns off the converter's and Oscillograph 1 power; and immediately disconnects the timing motors, systems, and Oscillograph 2 from the converters.

TM-2 stops, TM-1 resets itself opening TS1-1, if TM-1 was used. The converters stop, thus removing all ac power; the AC-1 indicator lamp, the fan motor, and the dc power supply are de-energized. The only power consumption is in the two green 28-volt indicator lamps. If the warmup and/or start commands are given, there is no response because TS2-4 is still open, preventing RY-1 and thus RY-2 from closing. Assuming now that the command circuits are open, the logic unit may be reset by pressing the reset button S-5. This unlatches RY-3, energizes RY-2 through diode D-5, and connects, since TS2-5 is now closed, TM-2 across the AC-1 converter line. RY3-1 opens its ac line to TM-1, and RY3-2 removes the ground from the RY-1 coil and attaches it to one side of the blue reset lamp. RY-2 starts the converters which start TM-2. TM-2 runs for about two seconds and closes TS2-4, which lights the blue reset lamp. Continuing to run for one more second, TM-2 resets, opens TS2-5, which stops the timer motor and turns on the yellow reset lamp. TM-2 is reset properly only when both blue and yellow reset lamps are on and the red calibration indicator lamps are off. Releasing the reset button will now open RY-2 and turn off the converters and the yellow reset lamps, leaving the blue reset lamp on to indicate that the logic unit is ready to recycle.

Diode D-5 is used to prevent RY-3's unlatch coil from being energized by the warmup command. Diode D-6 shorts the inductive kickback pulse across RY-3's unlatch coil, preventing the relay from latching again upon release of the reset button. When a commercial power line or generator power is available, the ac-dc switch S-4 may be thrown to the ac position, allowing the logic unit to function without the use of a dc power source. The neutral center cal switch S-7 is used to throw all channels on calibrate, either 50 percent or 100 percent.

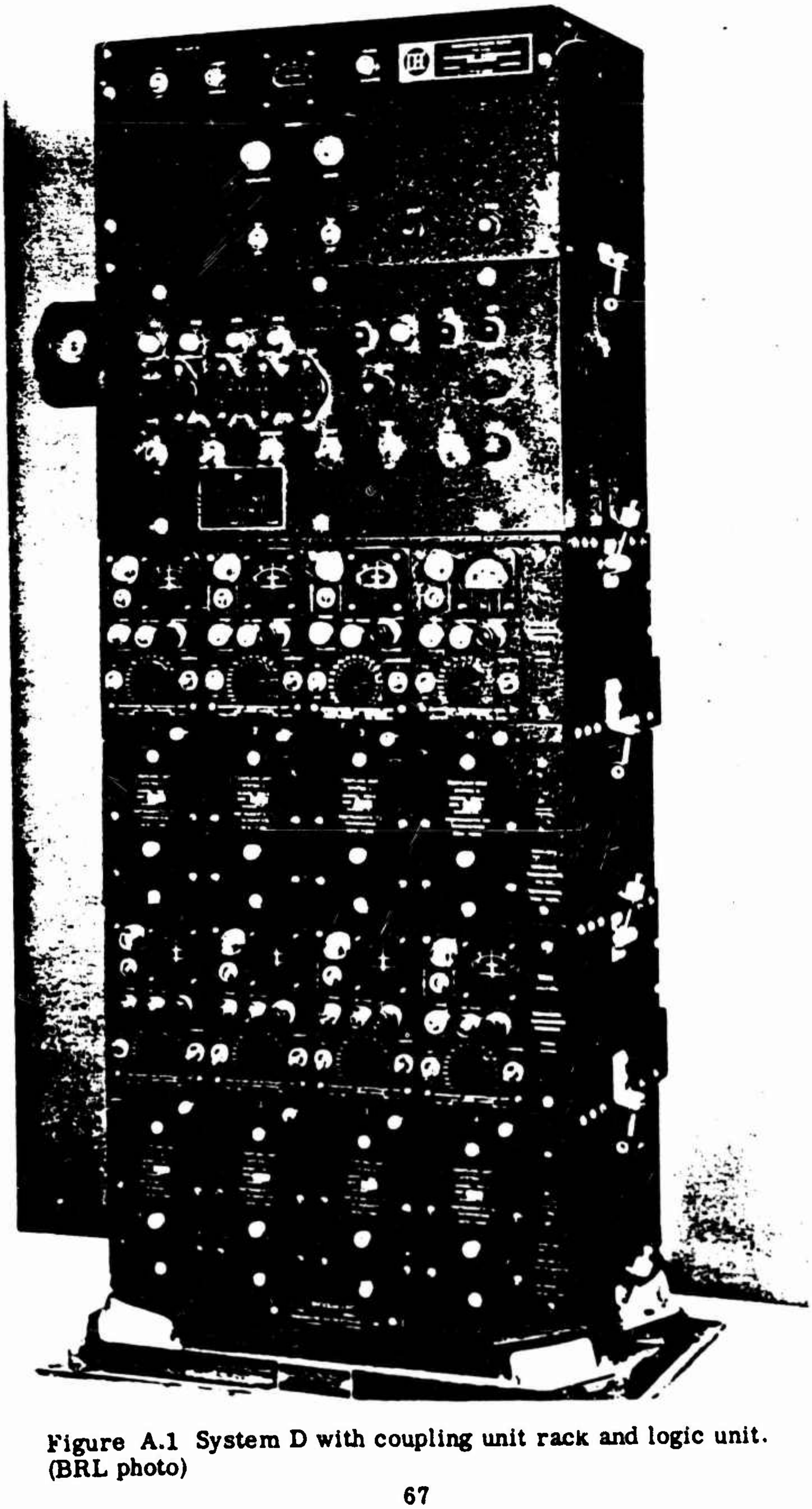


Figure A.1 System D with coupling unit rack and logic unit. (BRL photo)

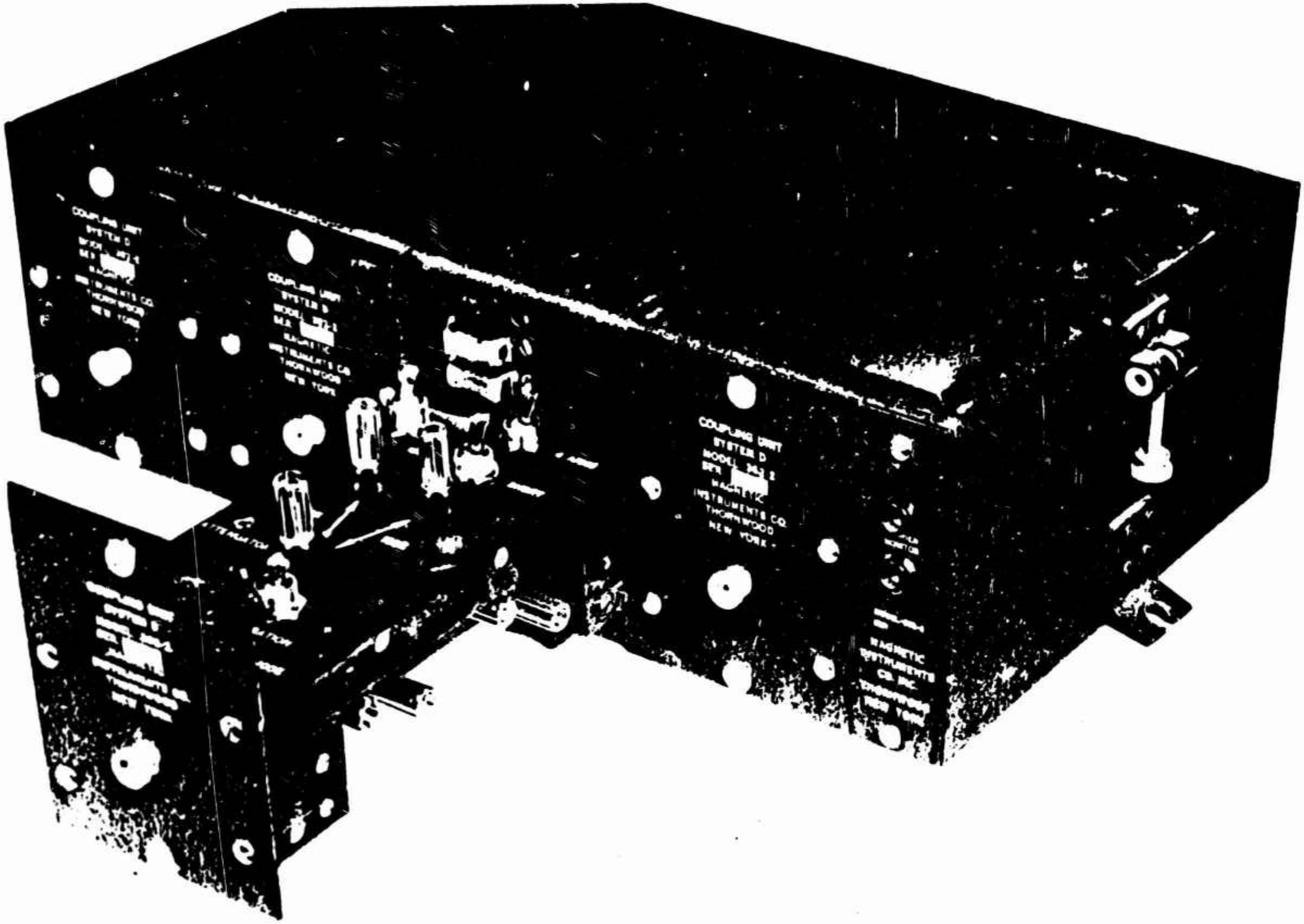


Figure A.2 Coupling unit rack with one calibrating position. (BRL photo)

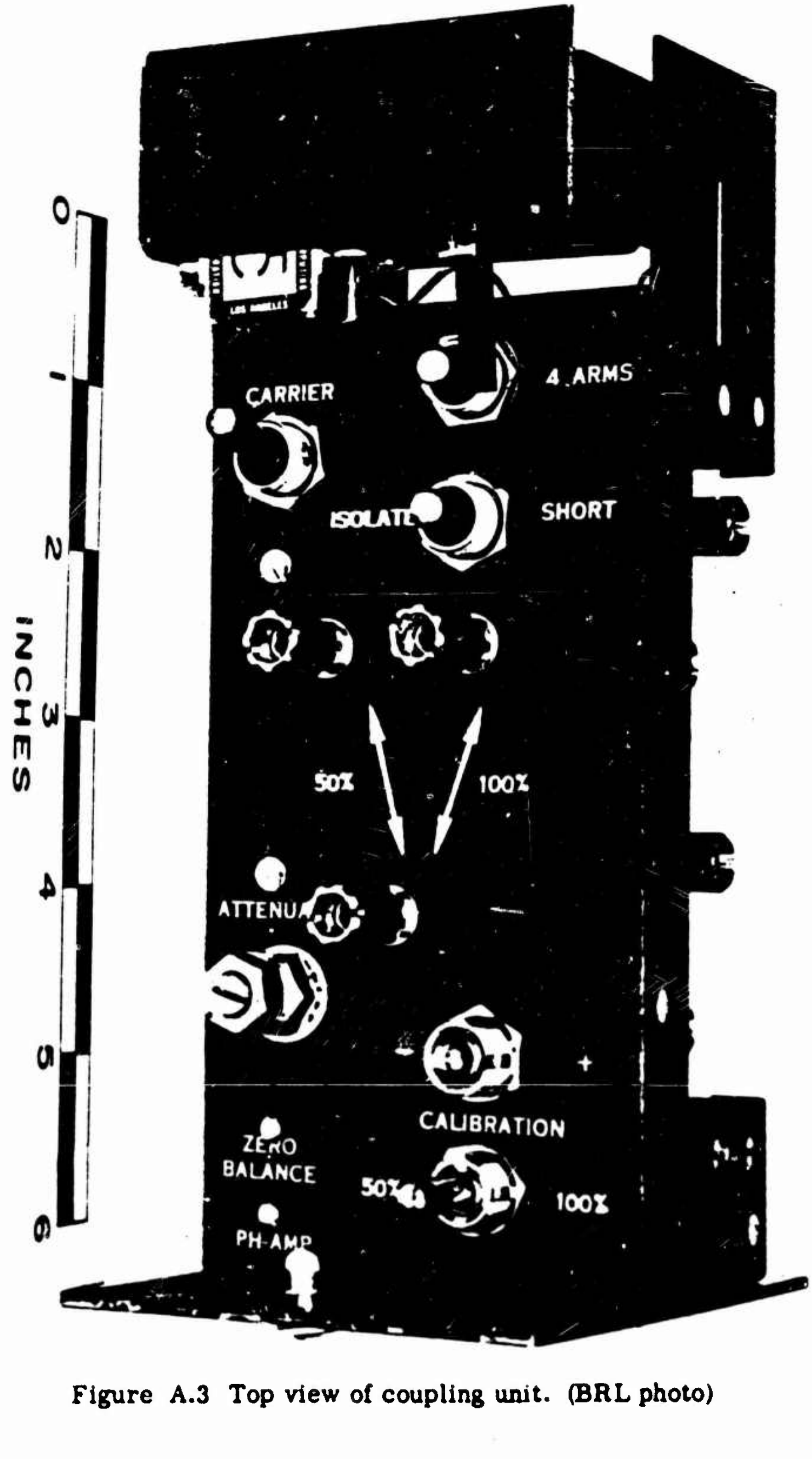


Figure A.3 Top view of coupling unit. (BRL photo)

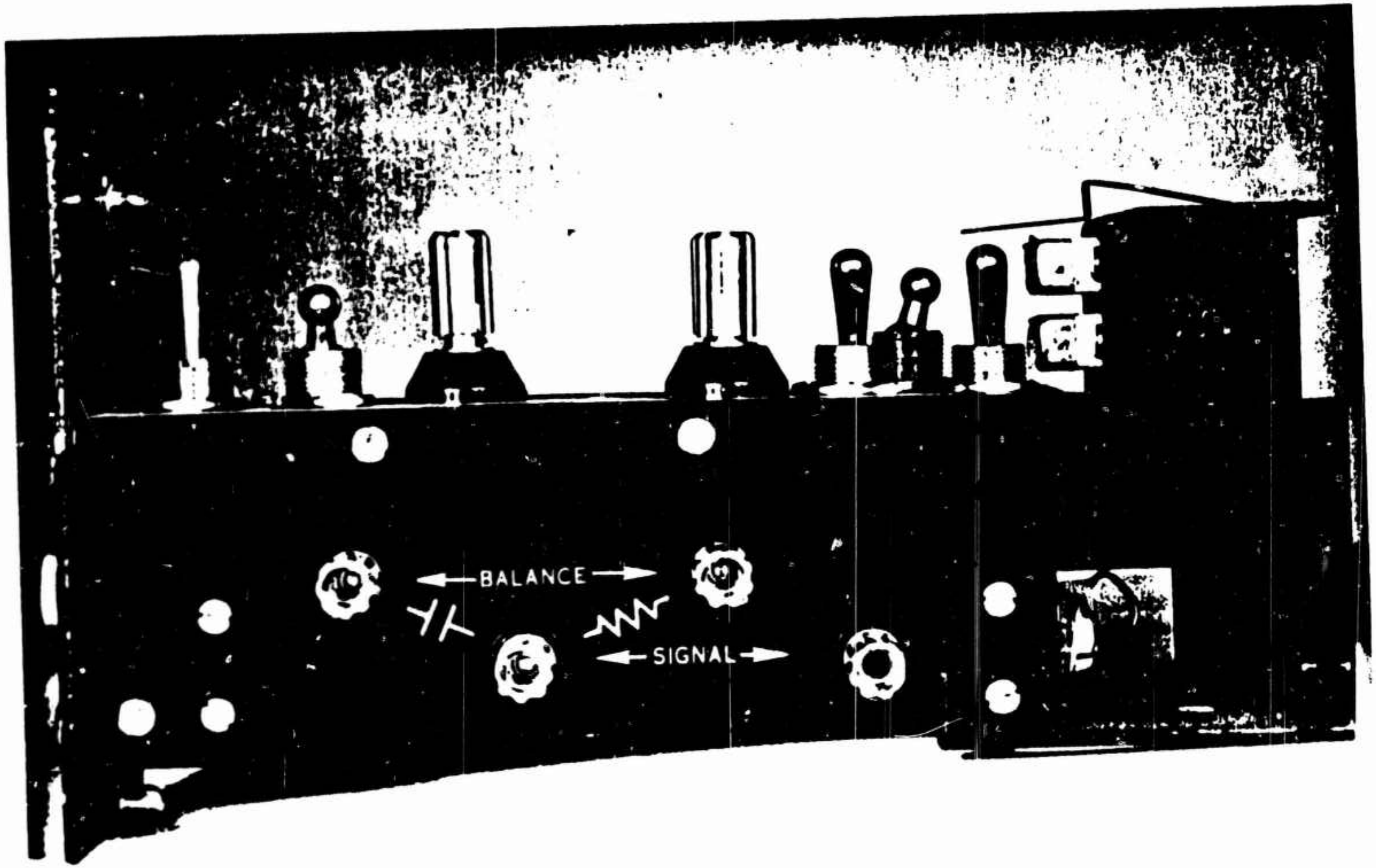


Figure A.4 Side view of coupling unit. (BRL photo)

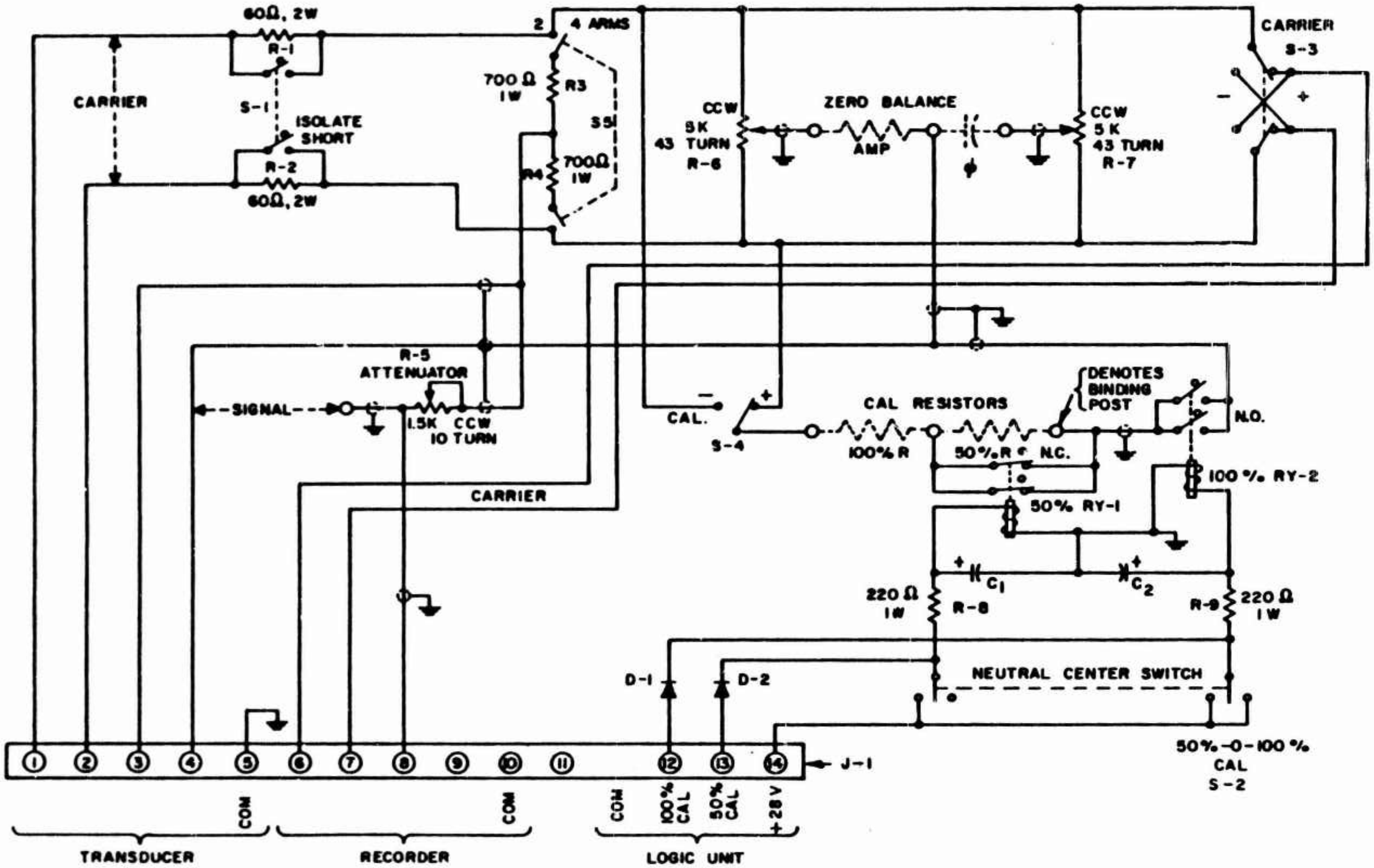


Figure A.5 System D coupling unit schematic.

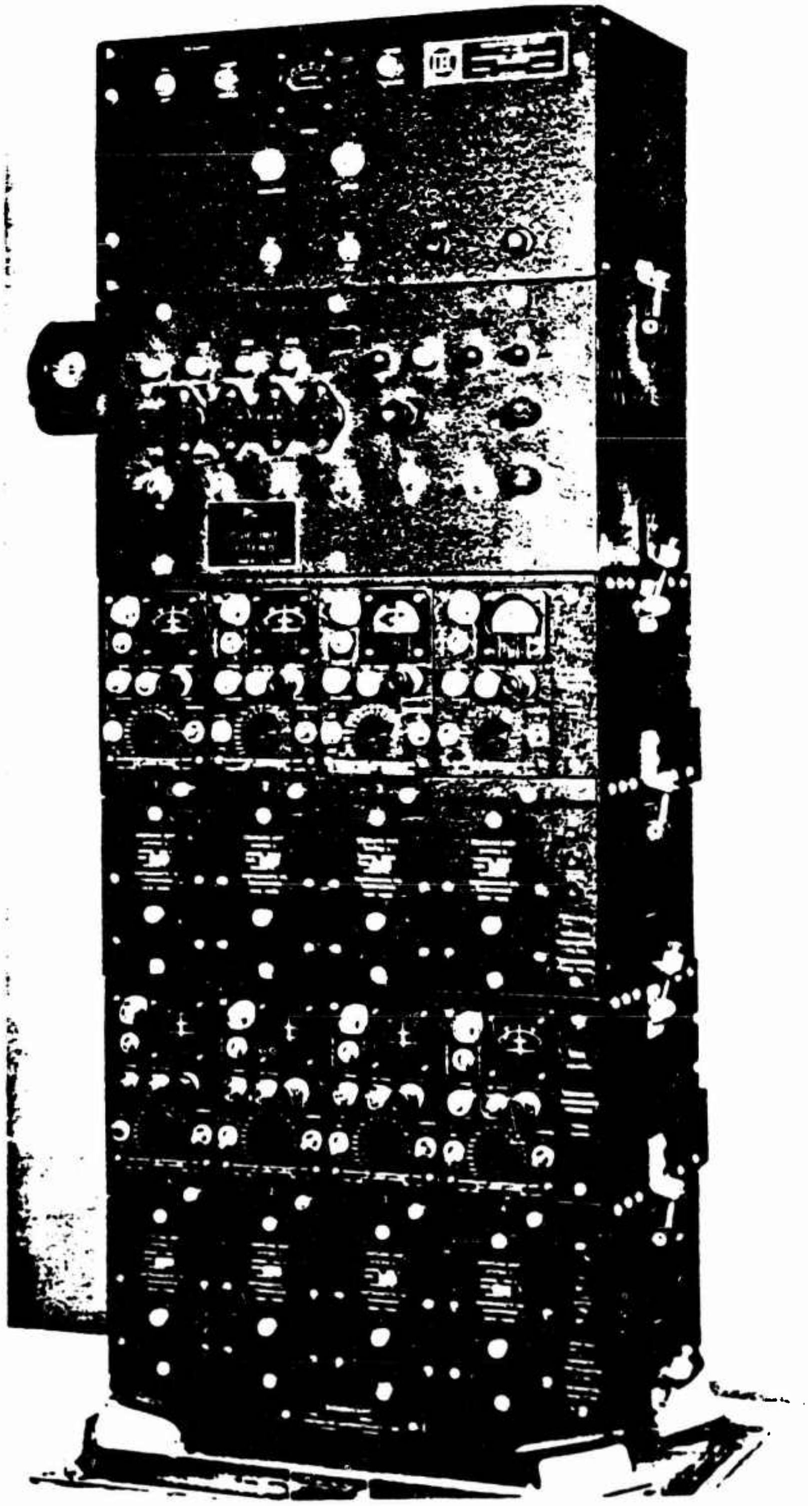


Figure A.6 Logic unit stacking with System D. (BRL photo)

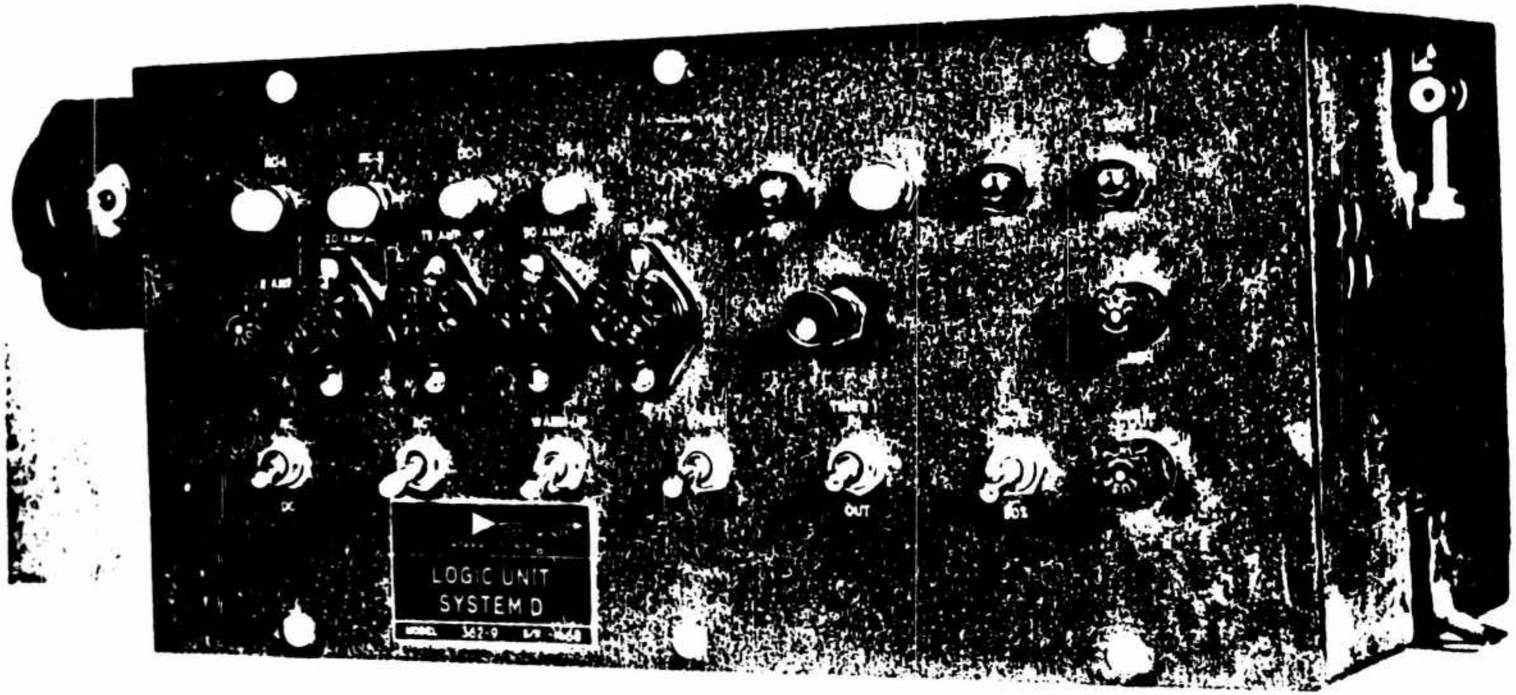


Figure A.7 Logic unit front control panel. (BRL photo)

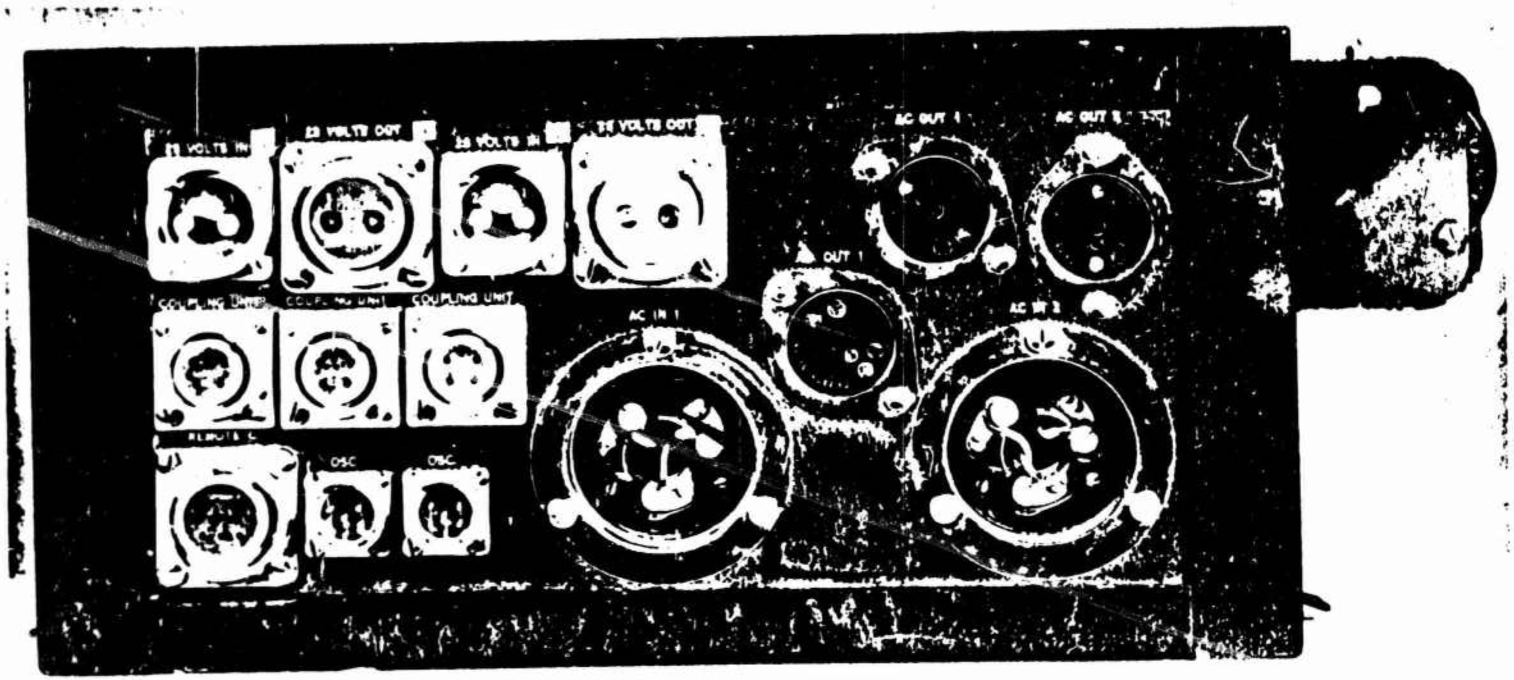
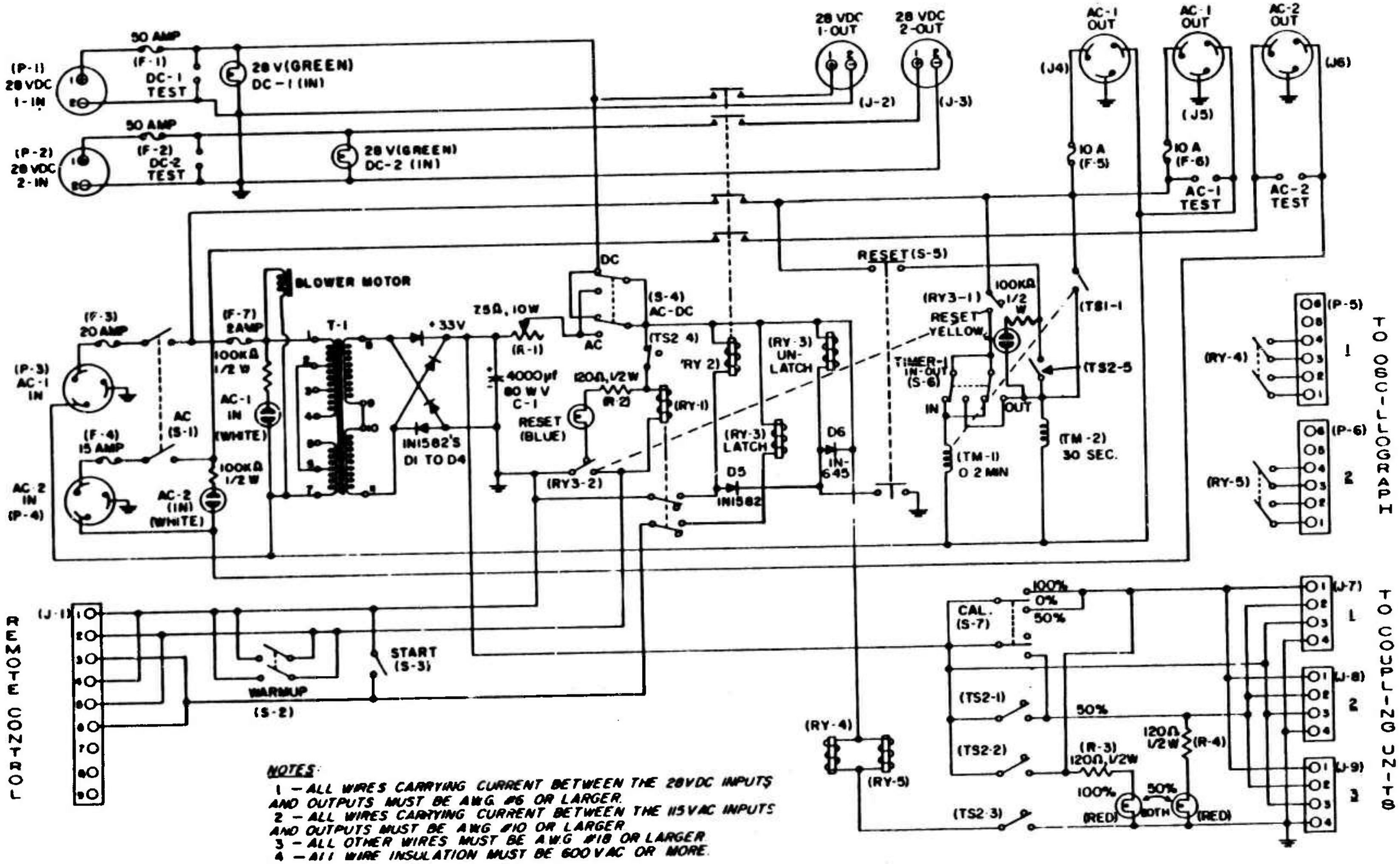


Figure A.8 Logic unit rear cable inputs and outputs. (BRL photo)



NOTES:

1 — ALL WIRES CARRYING CURRENT BETWEEN THE 28VDC INPUTS AND OUTPUTS MUST BE AWG #6 OR LARGER.
2 — ALL WIRES CARRYING CURRENT BETWEEN THE 115VAC INPUTS AND OUTPUTS MUST BE AWG #10 OR LARGER.
3 — ALL OTHER WIRES MUST BE AWG #18 OR LARGER.
4 — ALL WIRE INSULATION MUST BE 600 VAC OR MORE.

Figure A.9 Logic unit schematic.

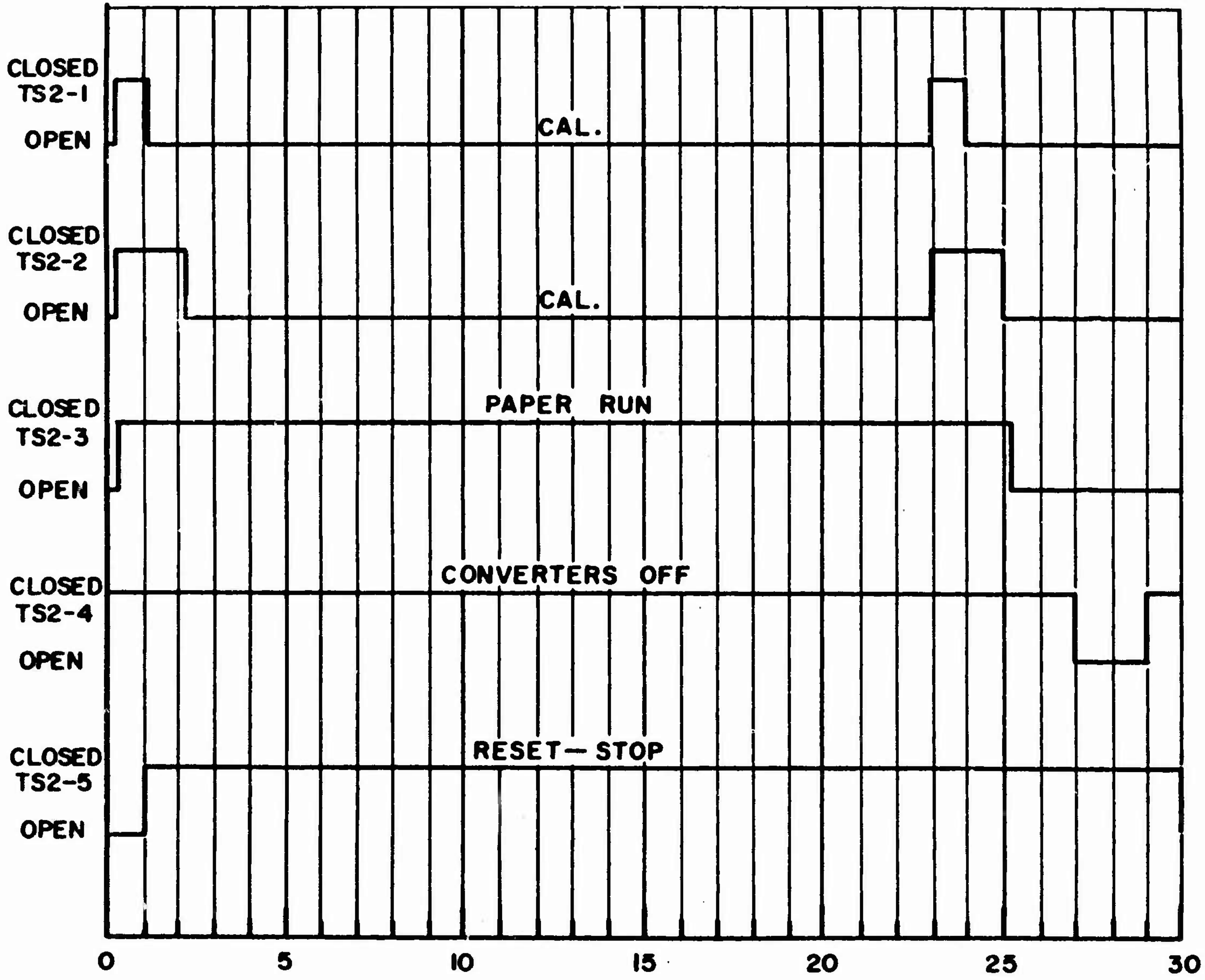


Figure A.10 Timer No. 2 switch program.

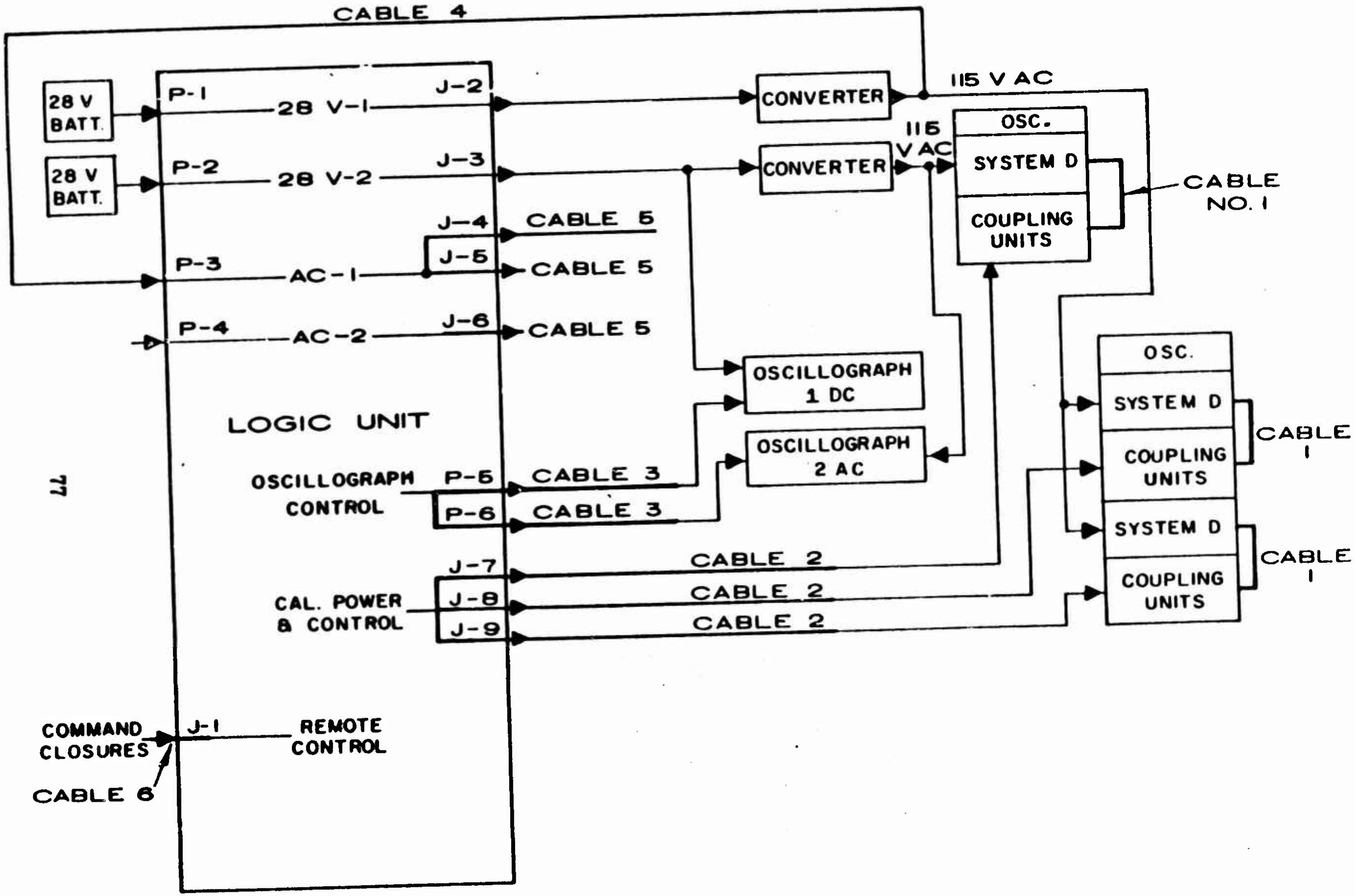
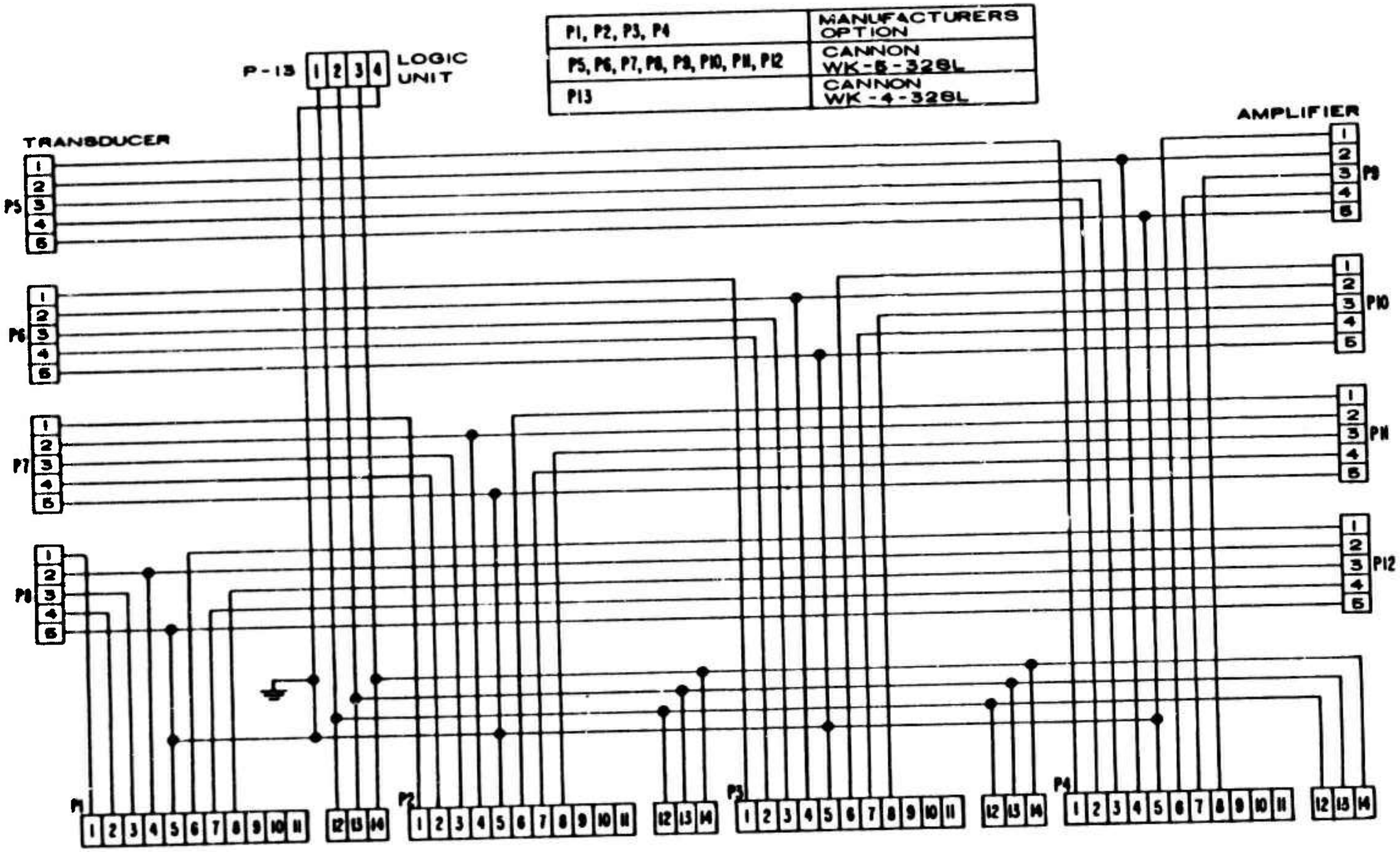


Figure A.11 Logic unit system layout.

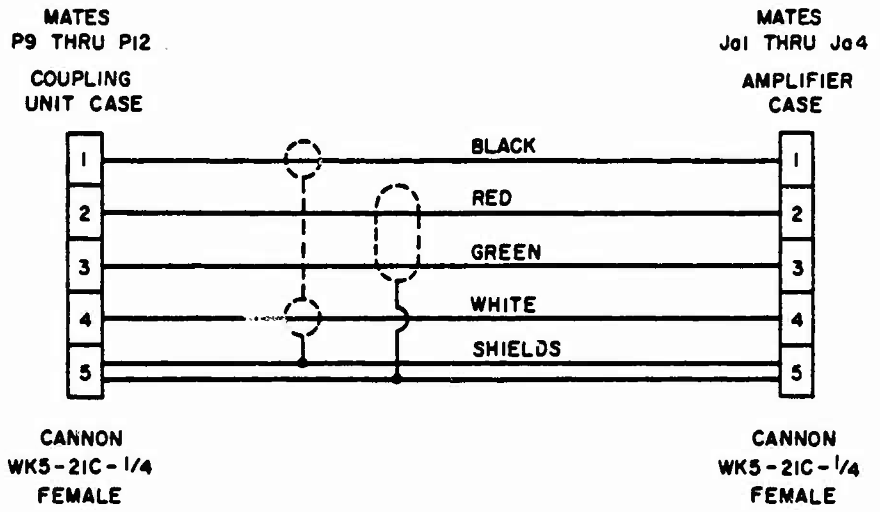


P1, P2, P3, P4	MANUFACTURERS OPTION
P5, P6, P7, P8, P9, P10, P11, P12	CANNON WK-5-32SL
P13	CANNON WK-4-32SL

SYSTEM D

Figure A.12 Coupling unit case internal wiring.

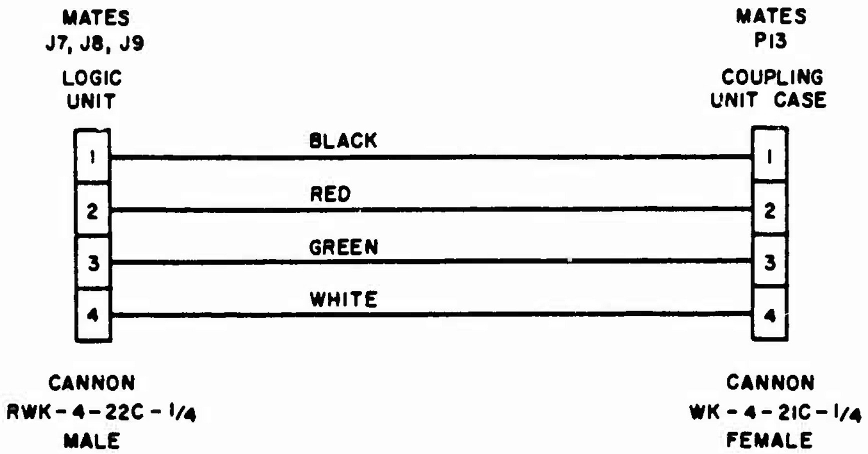
CABLE 1.



CABLE: WIRE: 4 COND. NO. 20 STRD, 10/30 TINNED COPPER 1/64" WALL INSULATION, 2 PAIR: 1 PAIR BLACK & WHITE, ONE PAIR RED AND GREEN, EACH PAIR SHIELDED TINNED COPPER, PVC JACKET OVERALL, NOMINAL WALL .20", GRAY JACKET. (BIRNBACH NO. S925-2S).

Figure A.13 Coupling unit to amplifier cable (carrier and signal).

CABLE 2.



CABLE: FOUR CONDUCTOR #22, 7/30 STRANDED BIRNBACH CAT. NO. 4732

Figure A.14 Logic unit to coupling unit case (electrical calibration power).

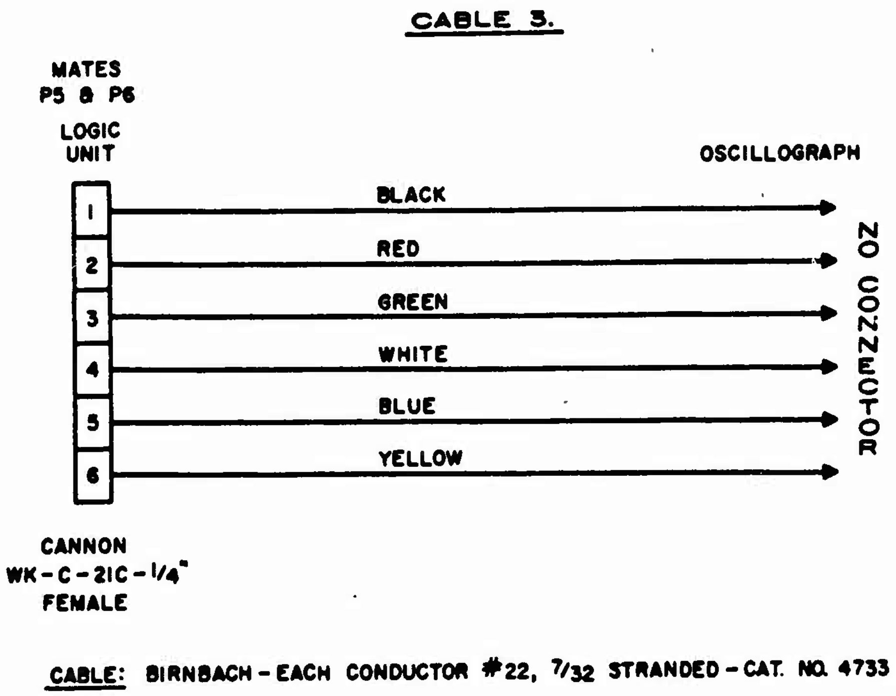


Figure A.15 Logic unit to recording oscillograph (remote control).

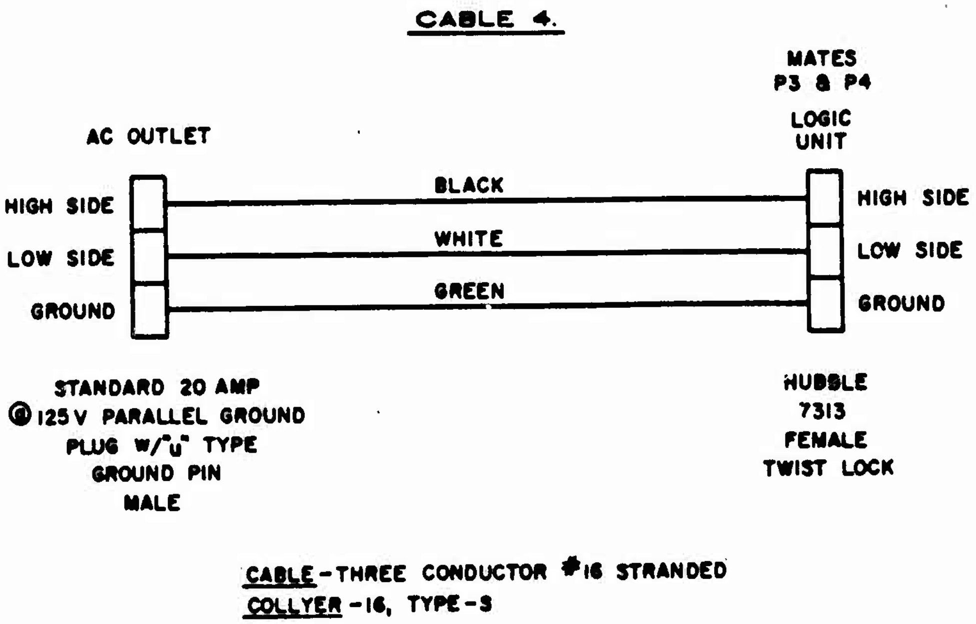
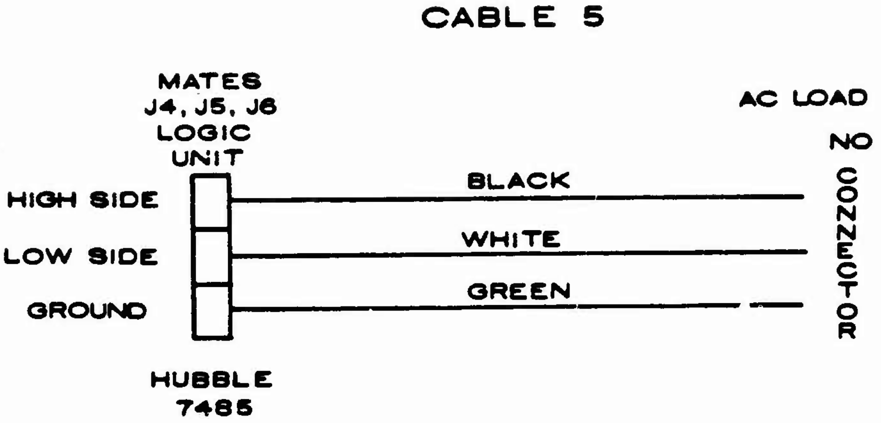
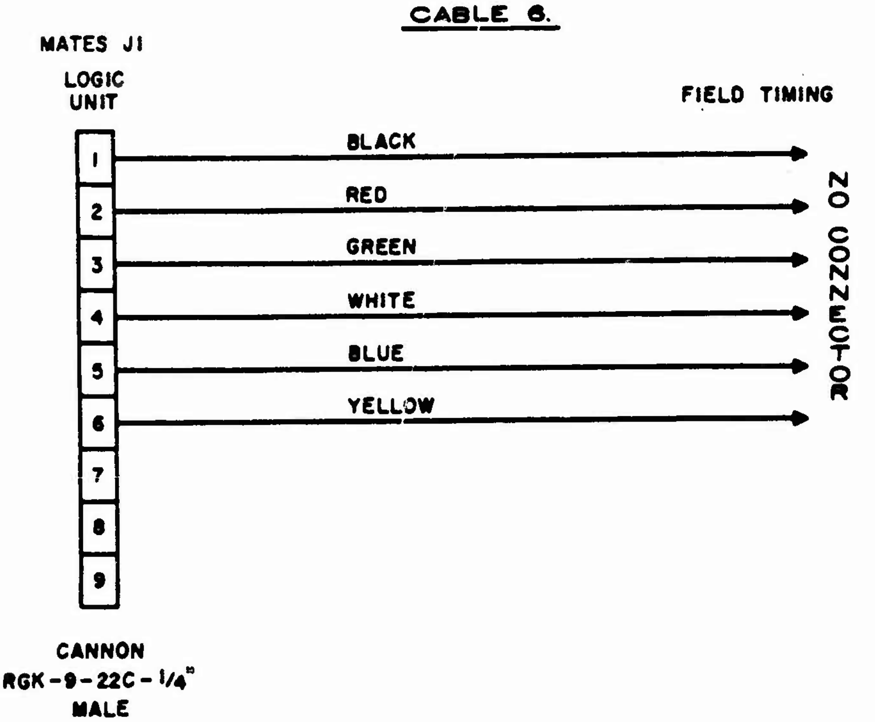


Figure A.16 AC power to logic unit.



CABLE- THREE CONDUCTOR #16 STRANDED
COLLIER- 16 TYPE-S

Figure A.17 Logic unit ac to recording equipment.



CABLE: BIRNBACH-EACH CONDUCTOR #22, 7/30 STRANDED-CAT. NO. 4733

Figure A.18 Remote control to logic unit.

APPENDIX B

PHOTOGRAPHS OF PRESSURE TIME PLOTS OF SELF-RECORDING GAGE RECORDS

APPENDIX C

FIELD TESTING OF SCALE MODEL DOMES

by Joseph F. Melichar, 1st Lt., USA

INTRODUCTION

The object of the program undertaken for the Smallboy event was to determine the feasibility and applicability of structural scaling of spherical shells to small sizes. The results were to be utilized as one measure in the investigation of the feasibility of general structural scaling.

BACKGROUND

The mathematical analysis of structures under transient dynamic loads is complex. To reduce the problem to the simpler terms of a less rigorous solution, the use of scale models is being investigated. The Terminal Ballistics Laboratory of the BRL has directed part of its research effort toward scaling structures to sizes suitable for study under air shock loading in its twenty-four-inch diameter shock tube. Data gathered from shock tube tests is related to the prototype through a semitheoretical analysis.

The model chosen for the program was a reinforced concrete ninety-degree central angle spherical shell one-eighth of an inch thick with a radius of curvature of 8 1/2 inches and a 12-inch-diameter base. The prototypes were tested on the nuclear Shot Priscilla in 1957. The grain size of the aggregate, the reinforcing, and the configuration of the model were scaled one-fiftieth. Lime was used to reduce the concrete strength and increase workability. The foundation was anchored to a wooden base by six symmetrically spaced 1/8-inch bolts. Concrete, with an ultimate compressive strength of five thousand psi, was used to fill around the ring and form the foundation. A transition region of approximately three quarters of an inch was used to taper the foundation to the thickness of the shell. The stronger and thicker shell base eliminated shear failure.

The short lead time involved in the Small Boy project curtailed background investigation to a minimum. Brief studies of low-strength mortars, theoretical analysis of shells, fabrication techniques, and pressure loadings on domes were carried on simultaneously with the fabrication of the model. The random scattering of concrete ultimate strengths in the model constructed is one of the outgrowths of the lack of preliminary investigation. The effects of this scattering proved beneficial, providing data on the effects of concrete strength on failure pressure.

The following relationship was developed from Reference 2 and was used as a guide for positioning of the model domes in the field.

$$f'_c = k \frac{PR}{h}$$

f'_c is the concrete ultimate compressive strength

P is the peak overpressure required to produce dome failure

R is the radius of curvature of the dome

h is the thickness of the dome

k is a constant of proportionality

Shock tube results indicated the equation approximately described failure conditions of the model domes. Sufficient data for a conclusive proof of the relationship have not been obtained.

The models were overly reinforced, thus concrete strength governed failure. Shock tube results (see Figure C. 1) indicated failure occurred within two milliseconds after shock arrival. The pressure during this interval was assumed to be some average value which was a function of the overpressure of the impinging shock wave.

BRL is indebted to the Structures Branch of MIT's Civil Engineering Department for its aid and guidance in the formative phases of this program. Harold D. Smith, under the direction of Dr. Robert J. Hansen, provided invaluable assistance.

PROCEDURE

Four models were used in the Small Boy event. The location and concrete strength of the models is described in Table C. 1. The models were mounted with the upper surface of the wooden bases flush with the ground. Wooden boxes filled with earth, weighing approximately 30 lbs, were bolted to the bottom of the wooden bases and acted as subsurface anchors. The wooden bases were painted silver to resist the effects of the thermal pulse. No instrumentation was used (see Figure C.2).

The models were examined after the test. Photographs were taken. Failure points were measured and mapped. Thicknesses of the remains of broken models were measured with a micrometer. The unbroken model was removed and sent to the Ballistic Research Laboratories for testing in the shock tube.

RESULTS

The results are summarized in Table C.2. The minimum failure pressure of the domes is estimated by examination of the remnants of the failed models. Dome No. 1 failed in the region of the minimum failure pressure (Figure C.3). Dome No. 2 failed approximately ten psi above the minimum failure pressure (Figure C.4). Dome No. 3 was sheared just above the foundation, leaving nothing to be analyzed (Figure C.5). Dome No. 4 did not fail (Figure C.6).

DISCUSSION

Domes No. 2. 3 and 4 were positioned to allow for error in predicting the minimum failure overpressure (See Table C.3).

Need for the margins was generated by: (a) variation in shell thickness (normally 10 to 30 percent thicker in sections), and (b) the possibility of the actual overpressure varying from the predicted values.

Measurements of the models used to date indicated thickness variations over the contour of the models, in addition to variations in average thickness between models. The location of the thicker sections affects the failure region and the minimum overpressure needed for failure. Postshot measurements allow the variations to be considered in the analysis. Improved techniques are presently being fashioned to reduce the variation to less than 10 percent in future models.

Based on prior experience, interpretation of the results yielded the estimated minimum failure overpressures for model domes No. 1 and 2. Model dome No. 3 was completely shattered, leaving little to analyze. No estimated minimum failure overpressure for it will be made. Dome No. 3 was 10 percent less than the desired nominal eighth-inch thickness. Domes were positioned with the belief that the thickness was 10 to 30 percent greater than nominal. The result was a complete destruction of Dome No. 3. It served as a good example of the effect of thickness variation on model failure.

An adequate number of models were not tested (three usable models on the field test and two usable models in the shock tube). Values of parameters (thickness, concrete strength, and conditions, etc.) vary between models and it cannot be assumed all models were valid. Several models of each strength should have been used, but limited time and funding precluded this. The results clouded by the insufficiency should be considered as strong indication, not a priori fact.

A small precursor existed in the region the models were positioned in. The side-on pressure in the precursor in the 70-psi overpressure region was 28 psi. The dynamic pressure within the precursor is not known. It has been assumed the precursor did not significantly affect the model failures.

CONCLUSIONS

The equation referred to in the Background section of this report appears to be substantiated within the bounds of the limited data available. Failure predictions proved to be correct. The conclusion to be drawn is shock tube tests on structural models provide the same results as field tests on similar models. Indications are shock tube tests on scale structural models predict the response of prototypes and larger models. To completely evaluate the correlation of prototypes, and larger model with small scale studies in the shock tube, more data is needed.

The possibility of structural design for dynamic response via shock tube model studies appears to be a distinct possibility.

TABLE C.1 CONCRETE STRENGTH OF MODELS

Dome Number	Concrete Ultimate Compressive Strength (psi)	Anticipated Overpressure (psi)	Failure Anticipated
1	5000		Marginal
2	4000		Yes
4	2600		No
3	3000		Yes

TABLE C.2 TEST RESULTS

Dome Number	Ultimate Compressive Strength (psi)	Shock Overpressure (psi)	Model Condition	Estimated Minimum Failure Overpressure(psi)
1	4950		Failed	72 - 77
2	3863		Failed	65 - 70
3	3000		Failed	-
4	2550		Not Failed	-

TABLE C.3 PREDICTED FAILURE OVERPRESSURES

Model Number	Predicted Minimum Failure Overpressure	Anticipated Overpressure at Model Location
2	67 - 72 psi	
3	57 - 62 psi	
4	35 - 40 psi	

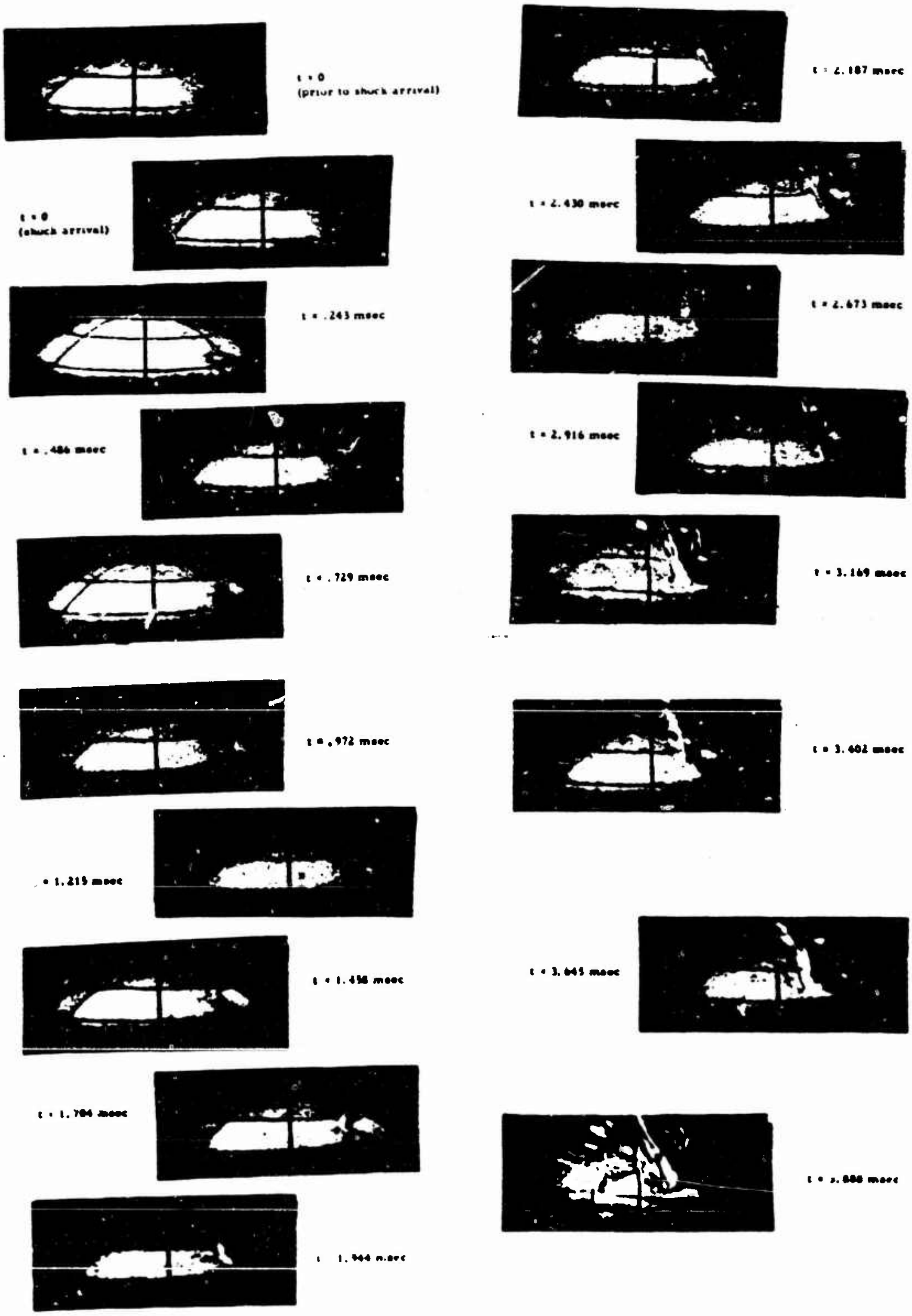


Figure C.1 Shock tube tests of scale models.

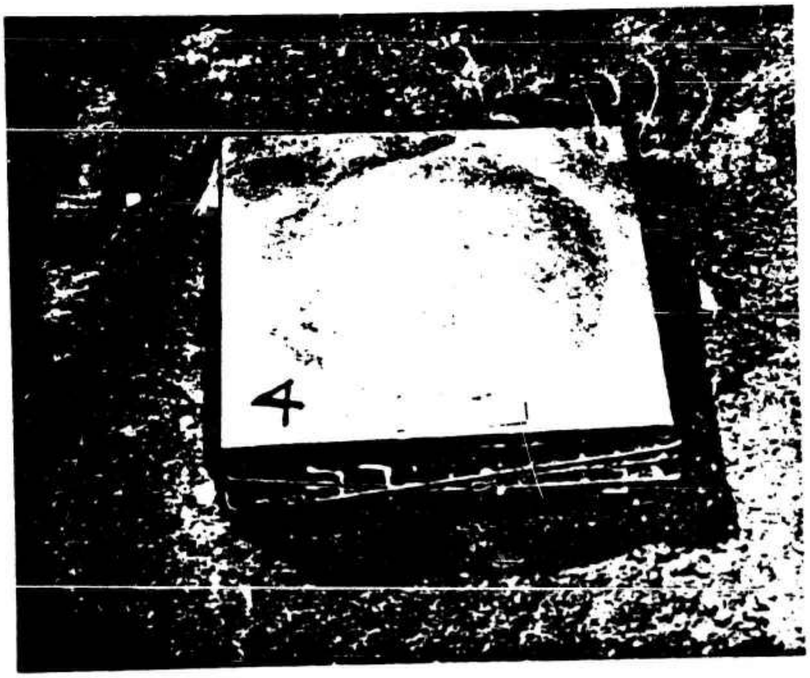


Figure C.2 Model dome and anchor box.
(DASA-889-04-NTS-62)

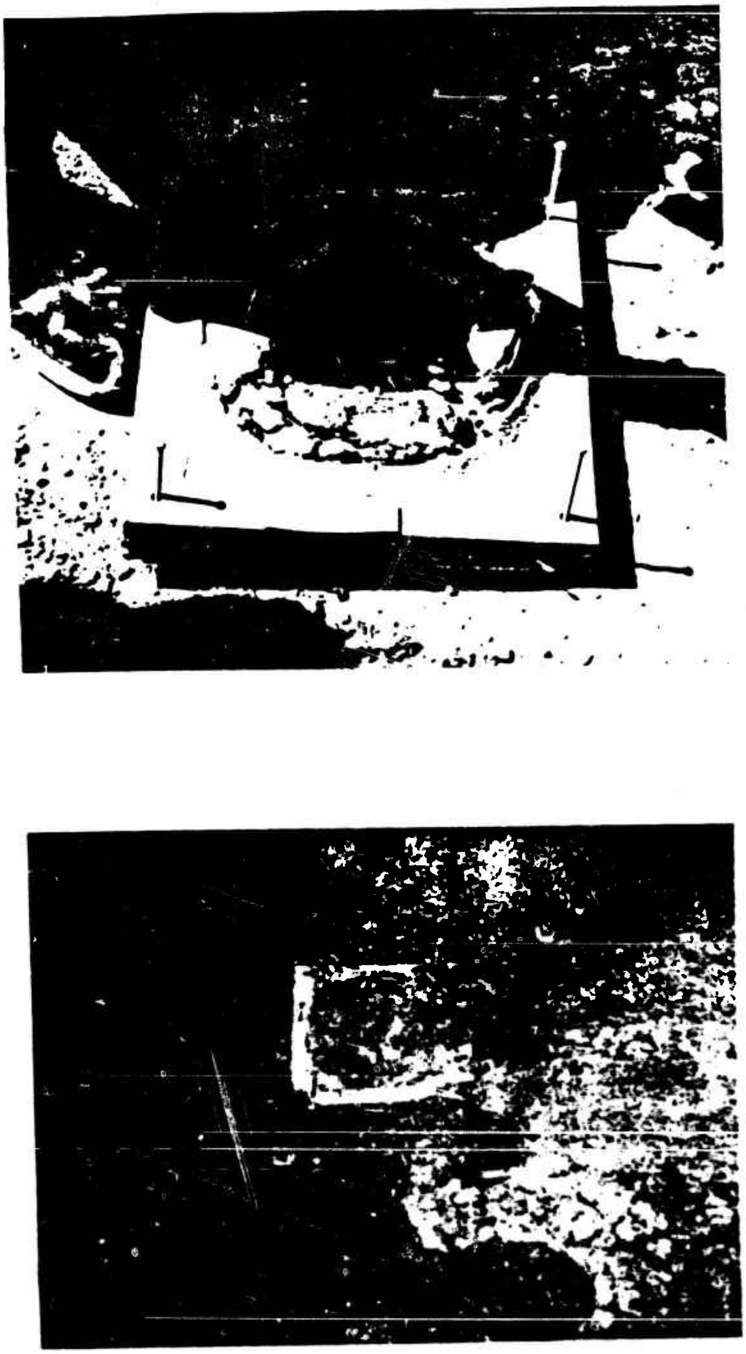


Figure C.3 Model dome No. 1. (DASA-889-11-NTS-62 and 889-01-NTS-62)

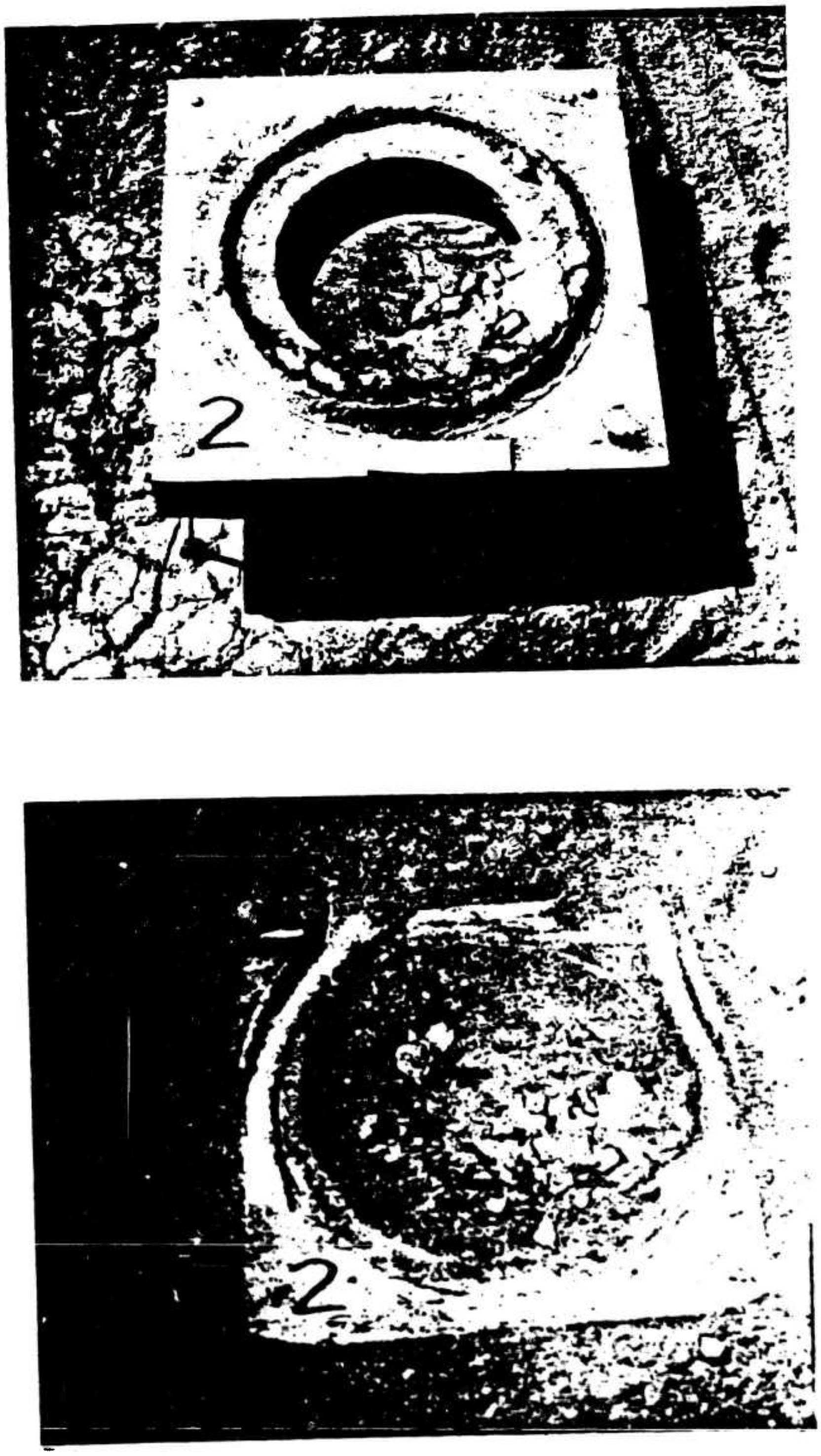


Figure C.4 Model dome No. 2. (DASA-889-06-NTS-62 and 889-03-NTS-62)

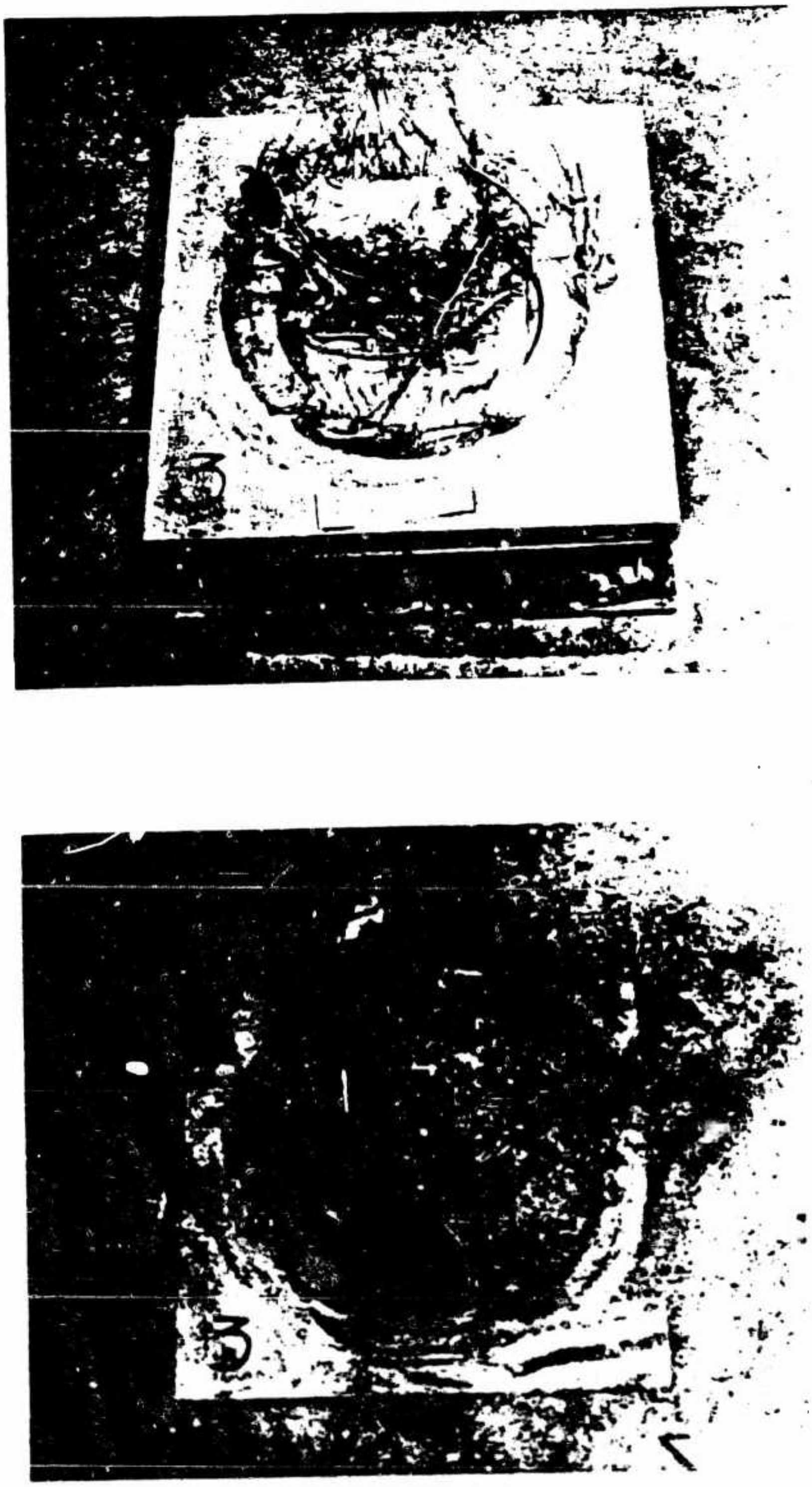


Figure C.5 Model dome No. 3.
(DASA-889-07-62)

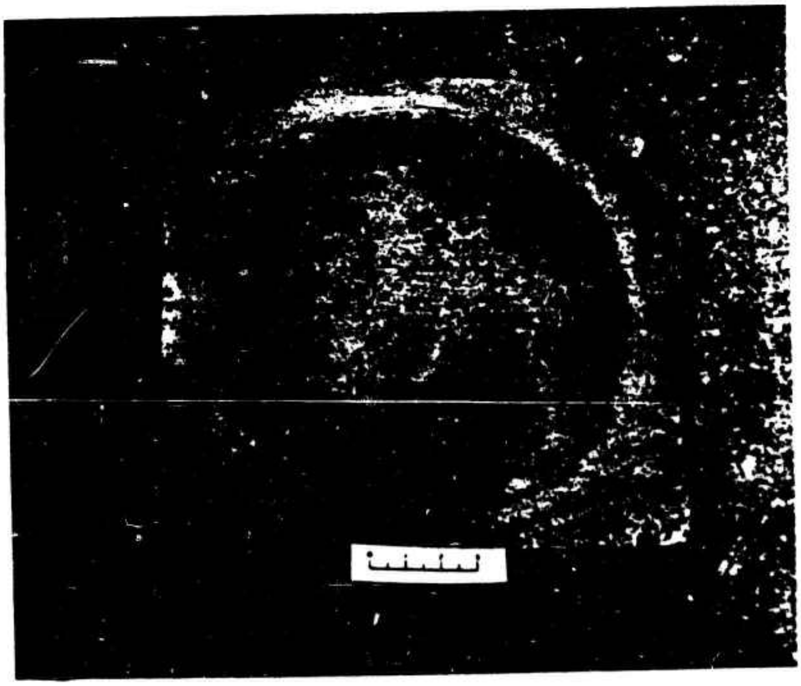


Figure C.6 Model dome No. 4.
(DASA-889-10-NTS-62)

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1. J.H. Keefer and others; "Nuclear Airblast Phenomena"; Project 1.1, Operation Sun Beam, POR-2200; Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland; Confidential Formerly Restricted Data.

2. Thomas G. Morrison; "Protective Construction Part III of III - Mathematical Analyses"; AFSWC-TR-59-2, ASTIA AD 306 645, Dec 1958; Air Force Special Weapons Center, Kirtland AFB, Albuquerque, New Mexico and Armed Services Technical Information Agency, Washington 25, D.C.