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EXPLODING WIRE SHOCK TEST FACILITY

Cushing Engineering, Incorporated

Prepared for
Office of Naval Research

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FINAL REPORT

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CUSHING
ENGINEERING,
INCORPORATED

EXPLODING WIRE SHOCK TEST FACILITY

FINAL REPORT

Prepared By

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under subcontract

from

Cushing Engineering, Incorporated

for

Office of Naval Research
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April 15, 1976

INTRODUCTION

The Cushing Engineering Company Shock Test Facility has recently been assembled and demonstrated at Naval Research Laboratory, Washington, D.C. for the purpose of investigating and testing underwater explosion phenomena from a pure energy yield explosion source. In conjunction with these experiments, Underwater Research Systems, Inc., of San Mateo, California has developed formulas to accurately scale the data results from these tests to approximate large nuclear explosions. The attendant instrumentation for this facility, presently available, allows for the study of gas bubble dynamics, surface wave and shock wave propagation, rarefaction shock wave generated cavitation and column formation.

The purpose of this document is to describe the aforementioned test facility equipment in regard to its construction, alignment and operational sequence.

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I. EQUIPMENT DESCRIPTION

A. Schlieren Optical System

The Schlieren System is an optical technique that detects density gradients occurring in fluids. The deflection of collimated light rays from its undisturbed path when it passes through a medium can be photographed in a Schlieren System when there is a component of the gradient of refractive index of the medium perpendicular to the rays.

The Schlieren Optical System in this test facility consists of a monochromatic approximate point light source, two pin hole knife edges, a small silvered-front surface mirror, two 80" focal length 9-1/2" diameter parabolic mirrors, two optical flat glass portholes, and a thin film beam splitter. Figure 1 shows this arrangement of the Schlieren System components.

The light manufactured by PEK, Inc., Type 107-1155, 17 volts, 5.8 amp, is a monochromatic mercury vapor arc lamp powered by equipment developed at AEROLAB Supply Company of Hyattsville, Maryland. The lamp has a relatively short life, which is dependent upon the operating current. A suitable operating current is 5.5 amps.

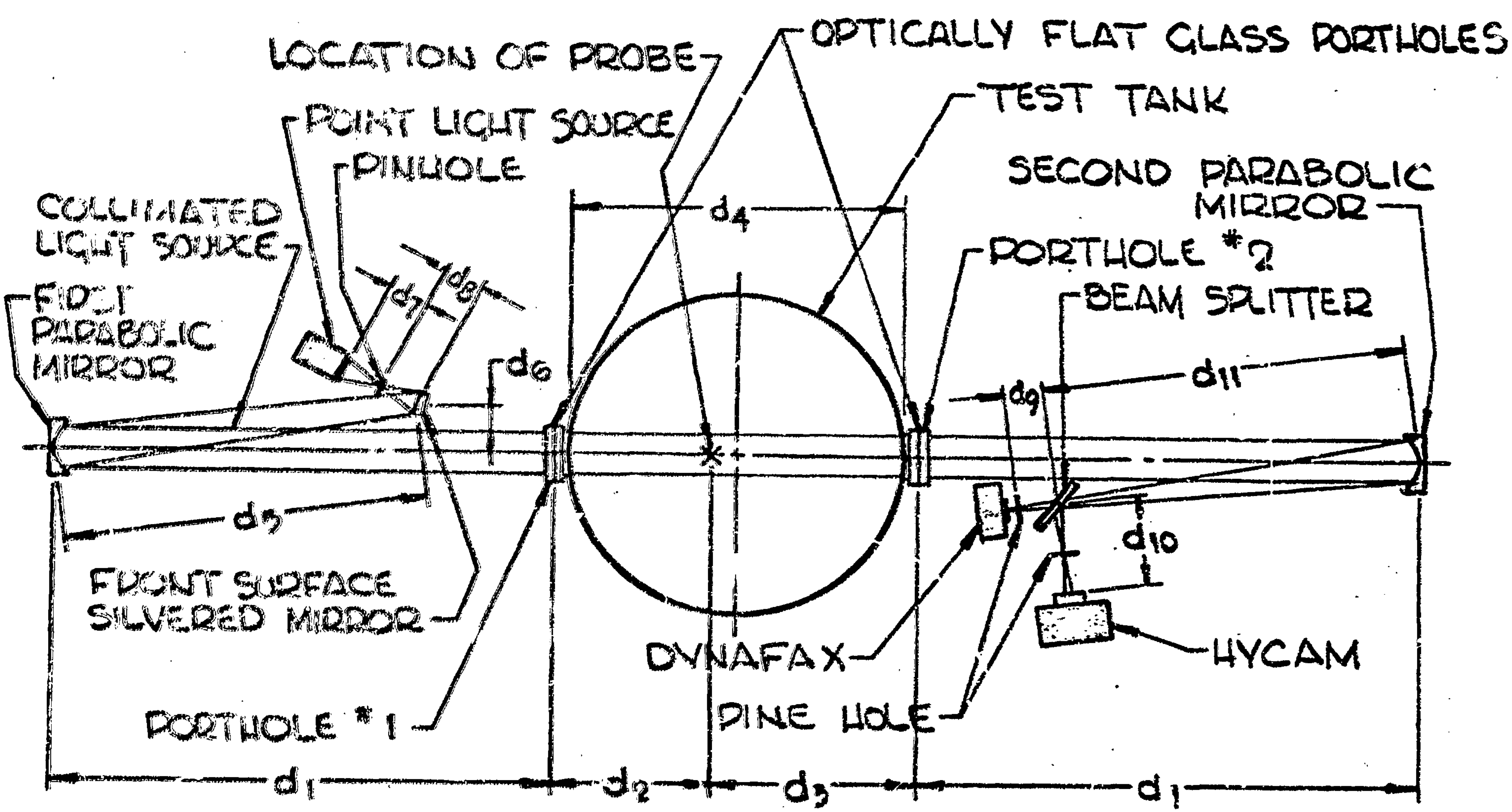
To obtain the approximate point light source, it is necessary to focus the light rays from the mercury arc lamp through the converging lens with a focal length of approximately 6-1/2 inches. A pin hole is positioned at the focal length to this lens. These light rays are then reflected from a small front surface mirror to the first parabolic mirror which, in turn, directs the diverging light rays to a parallel orientation. The rays then pass through the test tank with the optical flat glass portholes to the second parabolic mirror, which acts to divert the parallel beam to a converging one. A thin film beam splitter is then used to allow photographic observation of one light beam by two high speed cameras. The pinhole knife edges are positioned at the focal point and normal to both the converging light beams. In effect, the pin holes eliminate all spurious light rays and allow for sharp focusing of the image being photographed.

B. Dynafax Drum Camera

The manufacturing rights for this high speed camera have been purchased by Red Lake Laboratories of Santa Clara, California. However, information and repair can be accomplished by the Cordin Company of Salt Lake City, Utah. This camera is capable of framing rates of up to 25,000 pictures per second.

The film, Kodak Tri-X Pan TX 402, 35mm has to be cut to a length of 34 inches and installed in the Dynafax Film Cassette in a dark room. Then the cassette is installed in the camera and the film placed on the drum. The drum is adjusted to rotate at 7500 RPM for a proper framing rate of 25,000 pps.

A magnetic pick-up in the camera generates a signal pulse for each rpm. This output signal is monitored on a Houston Electronic Counter for accurate framing rate data. One revolution of the camera drum will deposit 224 frames on the film. The camera also has an internal light source which can be pulsed by a signal generator at a known frequency to put correct light tracks on the film to monitor camera framing rate.



TEST FACILITY LAYOUT
FIG. 1

FIGURE 1A

TEST FACILITY LAYOUT DATA

$d_1 \approx$ 8'-9'	Distance from porthole to parabolic mirror.
d_2 ~ various	Reference position of probe in the test tank is varied according to data required
d_3 ~ various	Reference position of probe in the test tank is varied according to data required
$d_4 \approx$ 6'	Diameter of tank
$d_5 \approx$ 77"	Distance from parabolic mirror to small front surface mirror
$d_6 \approx$ 1"	Distance from edge of collimated light beam to edge of small front surface mirror
$d_7 \approx$ 6.5"	Focal length of lens from point light source
$d_8 + d_5 \approx$ 80"	Focal length of parabolic mirrors
$d_9 \approx$ 6"	Distance from Dynafax pinhole to beam splitter Also from HYCAM pinhole to beam splitter
$d_{10} \approx$ 8"	Distance from HYCAM lens to beam splitter
$d_{11} + d_9 \approx$ 80"	Focal length of parabolic mirror

Attached to the camera is a Seikosha Shutter, Model No. SLV. During operation, the camera drum rotates at constant speed and a shutter allows exposure of the film for only one revolution of the drum to prevent double exposure. This shutter is remotely tripped by a Tektronix Shutter Actuator, which is energized by the sequencing/firing circuit. When properly adjusted and the shutter speed set at an exposure time of 1/125 sec., approximately 200 pictures will be deposited on the film in one revolution of the drum camera, thereby giving a framing rate of 25,000 pps.

The attached lens on this camera is a Cosmicar Television lens, Model No. 14244, adjusted to f/1.4 and focal distance at infinity.

C. Red Lake Camera (Hycam)

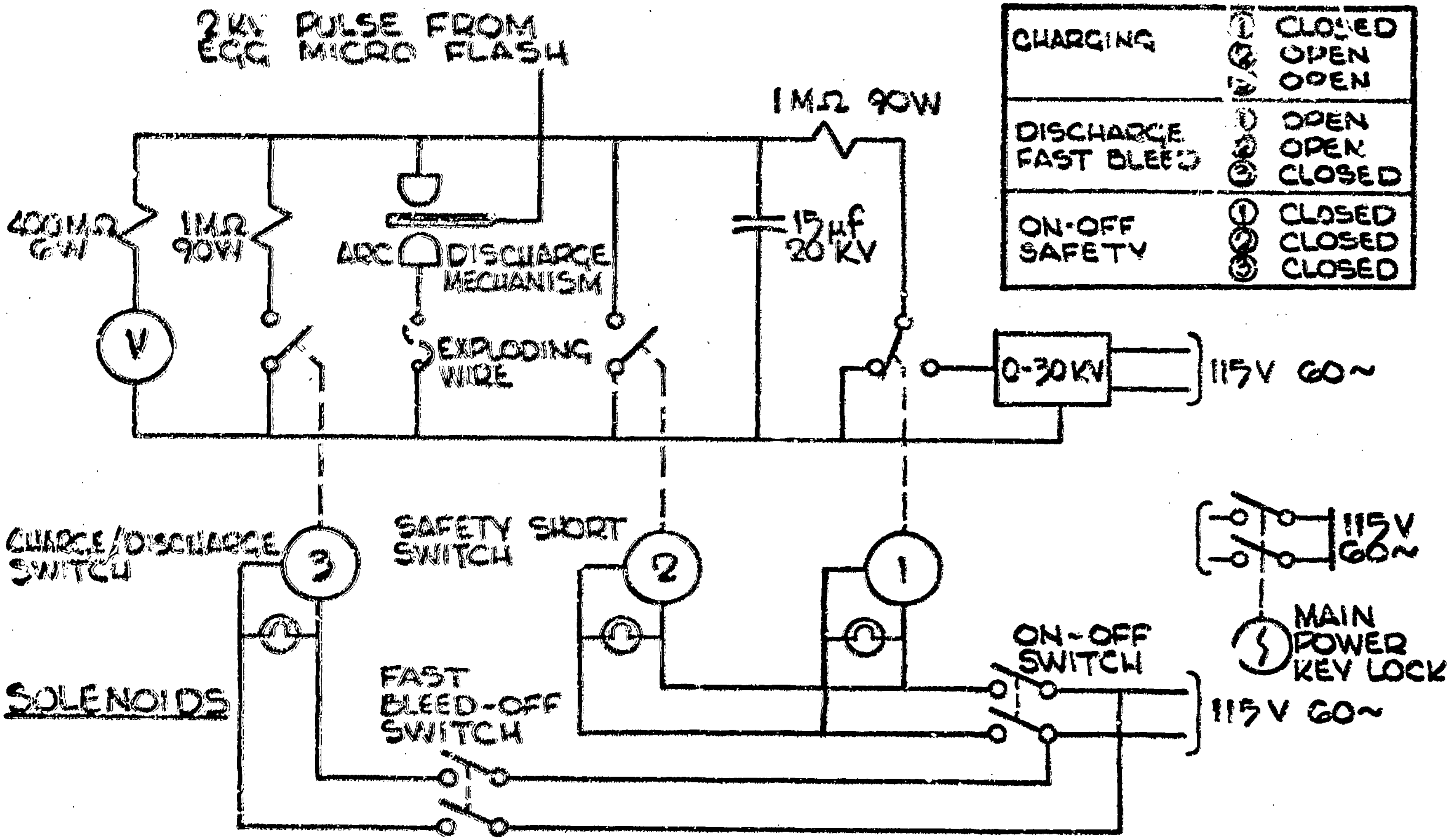
The Hycam camera is manufactured by Red Lake Lab of Santa Clara, California. It is capable of framing rates from 1 to 3,000 pps, and is regulated by a servo motor controlled power supply. The framing rate of this camera is monitored by a Millimite (TLG-4) flash unit which places photo light tracks on the film margin at a known frequency. This attachment is also manufactured by Red Lake Lab. The lens attached to this camera is also a Cosmicar Television Lens No. 19020 adjusted to f/2.0 and a focal distance at infinity.

D. Charging System

The charging system is comprised of a 30 kilowatt power supply and a 15 microfarads -20 kilovolt capacitor, capacitor voltmeter, capacitor discharge mechanism, exploding wire probe, and a series of safety protection solenoids. The basic circuit is shown in Figure 2. The power supply charges the capacitor to the desired voltage through a one megohm resistor. The capacitor voltage is measured by a voltmeter which is wired in parallel with the capacitor. A 400 megohm resister protects the voltmeter from high current.

The arc discharge mechanism is fabricated of two brass hemispheres separated by a space approximately one and one-half times that required for 15KV to arc across. Between the brass hemispheres is a hollow glass rod of a high percentage silicore composition. In the center of the rod is a bare wire conductor, which when pulsed with a 2KV charge from the explosion sequence circuit, breaks down the air space between the brass hemispheres. This action causes the capacitor voltage to discharge across the exploding wire probe. The 2KV charge from the EGG unit travels out both ends of the glass rod along its outer surface and arcs in a uniform field to the brass hemispheres as shown in Figure 3.

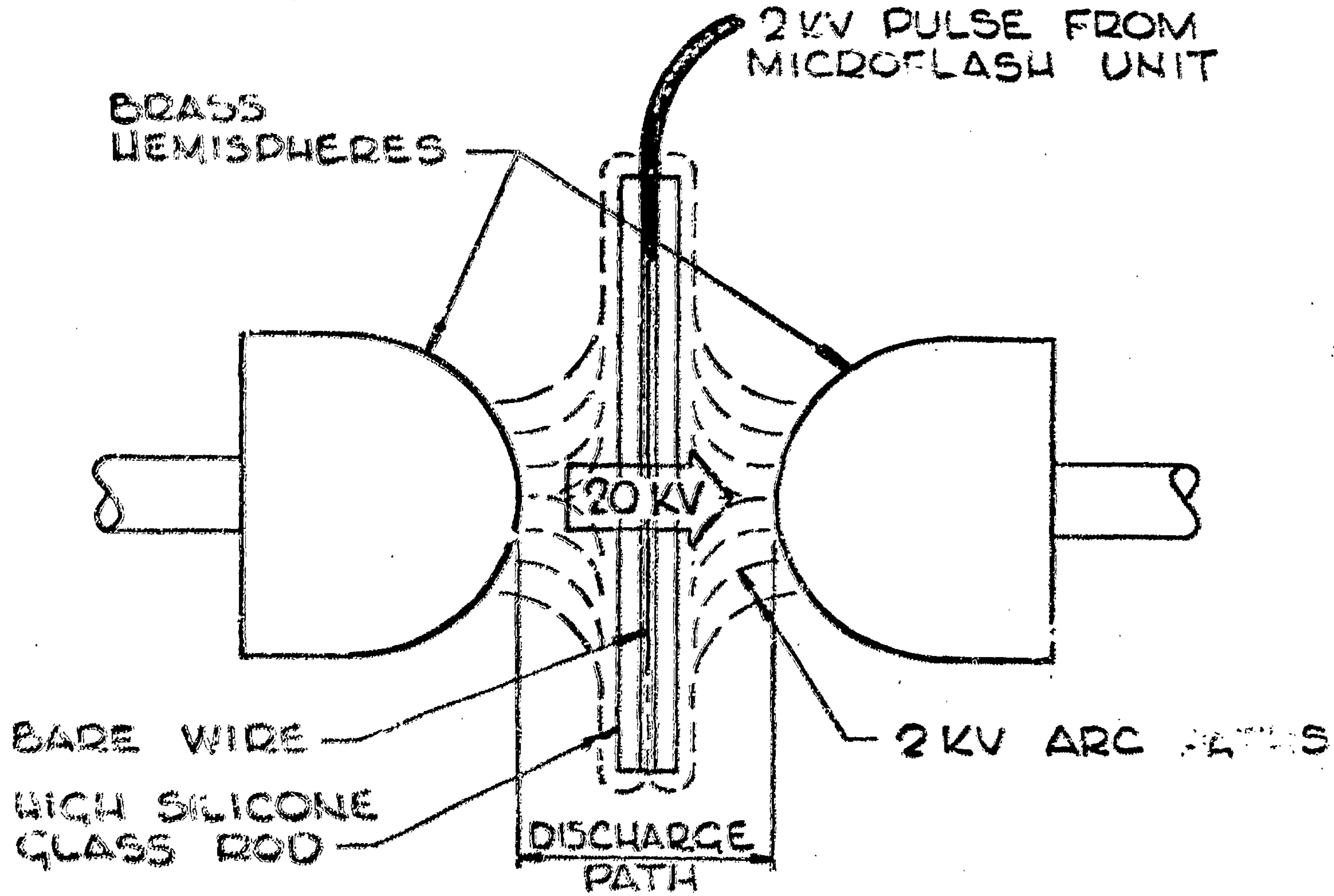
The exploding wire probe is shown in a sectional assembly drawing, Figure 4. The exploding wire is a #40 (.003" diameter) nichrome wire filament which is attached to the probe tips by contact welding. When the capacitor voltage is dumped, the charge is conducted to the probe wire filament which instantly vaporizes resulting in an explosion. The energy from the brass hemispheres is conducted to the wire filament on a special wire selected for proper capacitance between the inside and outside conductors. The wire is manufactured by Amphenol No. 621-106 59/U Triax Type.



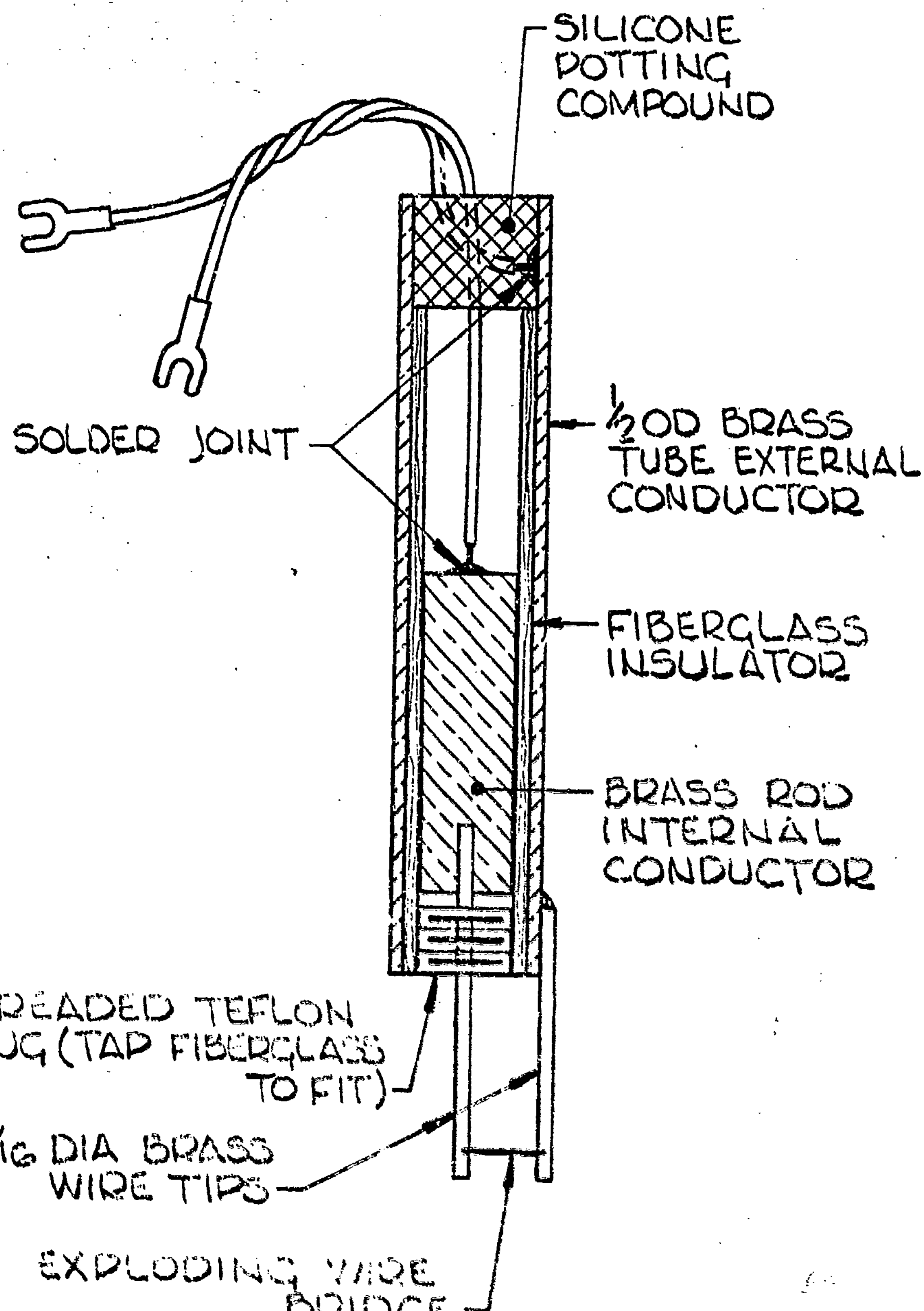
SWITCHING KEY

CHARGING	①	CLOSED
	②	OPEN
	③	OPEN
DISCHARGE FAST BLEED	①	OPEN
	②	OPEN
	③	CLOSED
ON-OFF SAFETY	①	CLOSED
	②	CLOSED
	③	CLOSED

CHARGING CIRCUIT
FIG 2



CAPACITOR DISCHARGE MECHANISM
FIG. 3



PROBE ASSEMBLY
FIG. 4

E. Sequencing/Firing System

The sequencing and firing system is necessary to allow adequate explosion time delay for the relatively slow time constant of the Seikosha Shutter. The time delay schematic is shown in Figure 5.

During test operation, should a problem occur, the energy of the capacitor can be discharged into a one megohm resistor by placing "charge-discharge" switch on power supply to "discharge."

With the capacitor fully charged and the Dynafax camera operating at the desired rpm, the Hycam is started. After the Hycam accelerates to constant speed, a microswitch is automatically closed. This switch closure trips the Tektronix Shutter Actuator which simultaneously actuates a solenoid to fire the Seikosha shutter and provides an input signal to the Rutherford Electronics digital time-delay generator. The Rutherford delays the input signal as required and delivers a gate output signal to the EGG microflash unit which dumps an electrolitic capacitor 2KV charge to the wire located in the glass rod shown in Figure 3.

The schematic in Figure 5 gives an overview of the entire electronic circuit for charging/discharging and sequencing/firing.

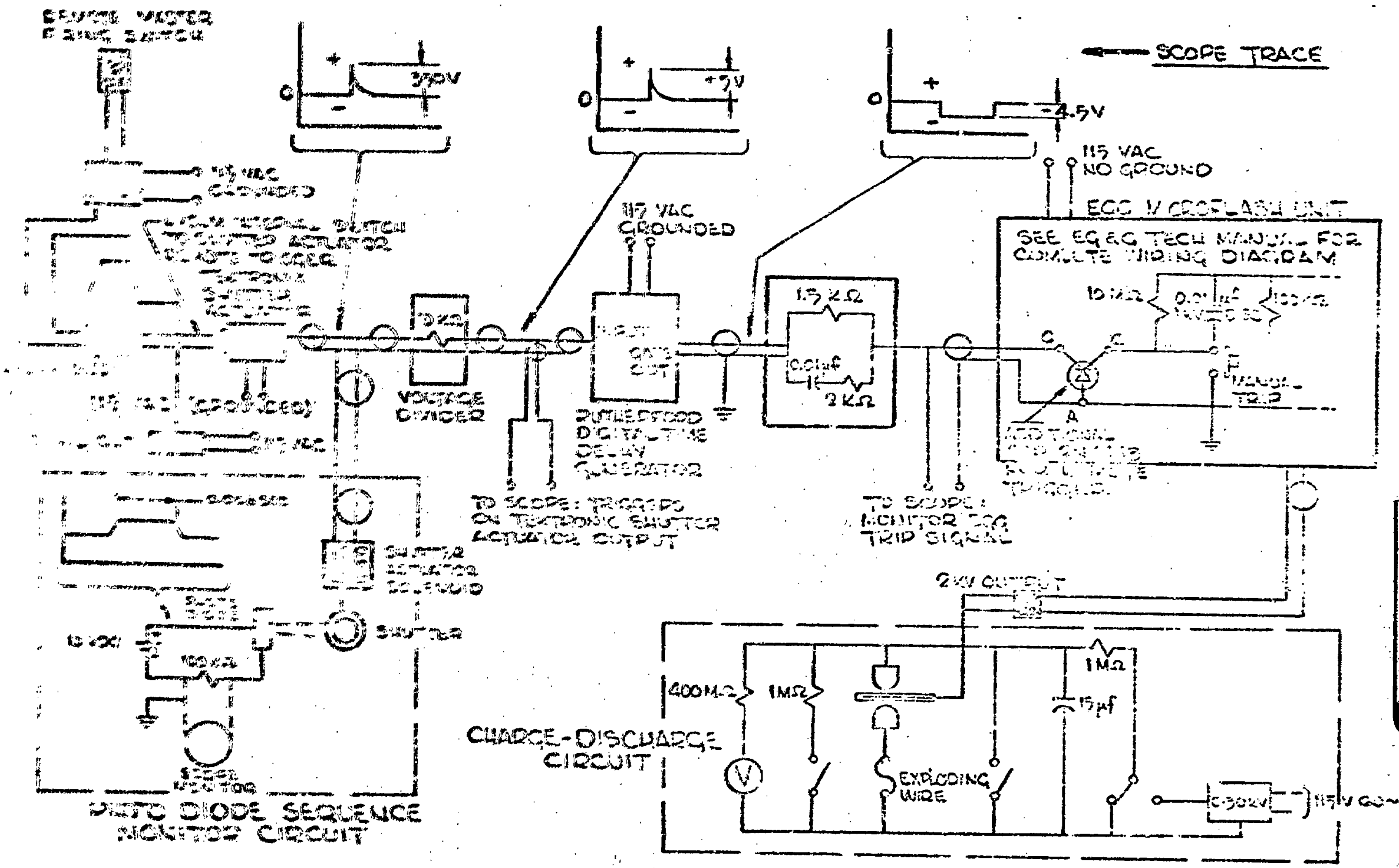
F. Additional Equipment

Supplemental equipment available for this test facility includes the following:

1. Two surface wave gauges developed by Cushing Engineering are used to monitor surface wave propagation. These gauges consist of two rods containing the primary and secondary windings, and the bare ground rod. The primary and secondary windings are comprised of two wires of different diameters wrapped around a metal rod and potted with an epoxy resin. After the epoxy has set, the outer coating of the (secondary) larger diameter is removed to allow contact with the water. Via the electronics, the primary induces a voltage in the secondary. The voltage measured between the ground rod and the bottom of the secondary is constant over the length of the windings. Thus, the output voltage measured is proportioned to the immersion of the secondary into the water. If totally immersed, the wave gauge output voltage would equal one-half of the total secondary voltage. The resolution of this instrument is dependent on the wire diameter of the secondary windings, which in this case is less than .1% of full scale. The best means of measuring the output of the wave gauge electronics is to use a high frequency chart recorder with heat sensitive paper.

2. A 16mm Bolex camera is also available to allow observation of the water surface conditions during each text shot.

3. Piezoelectric pressure transducers are available to measure shock wave pressure data. These transducers essentially convert acoustic energy into electric energy of the same frequency which can then be monitored on an oscilloscope. The transducers available with this facility were manufactured by Atlantic Research, Inc.



COMPLETE SYSTEM OUTLINE SCHEMATIC
FIG. 5

4. A Stokes HIVAC vacuum pump is attached to the test tank to allow varying of the pressure over the water from atmospheric to 1 or 2 psi.

5. An essential piece of equipment for this test facility is the water filter system. This filter system performs two major functions: it cleans the water to a high optical purity to increase the photographic quality of the test medium, and then it keeps the fluid in constant motion to prevent thermal stratification of water which would cause improper defraction of light beams.

6. A Tektronix storage oscilloscope Type 549 is available. An oscilloscope with a display storage memory is not only used to adjust the firing mechanism delay but also used to display output of piezoelectric transducers for subsequent photographing by an oscilloscope camera.

Of the above mentioned items, the only equipment not available is a high speed chart recorder.

While the previous section gave a general description of the equipment used for this test facility, the following portion will elaborate on the alignment and sequencing aspect of the test operation.

II. ALIGNMENT AND SEQUENCE

A. Optical System Alignment

The positioning of the test tank is of major importance. To allow for ease in aligning the Schlieren Optical System, it is necessary to place the tank so that the centers of the portholes lie in a level plane. The nuts securing the optical flat glass portholes are to be evenly adjusted hand-tight.

The 9-1/2" diameter parabolic mirrors are then placed on either side of the tank as shown in Figure 1, approximately 8 feet from the glass portholes. The centers of both the parabolic mirrors and the portholes should lie in a straight line. This fact can be established by using a transit to indicate the center of the porthole (as scribed on the plexiglass porthole covers) and swinging the transit in a level plane to the scribed center on the cover of the parabolic mirror. It is then necessary to adjust the feet on the mirror stand to obtain the proper position. This adjustment must be performed for both parabolic mirrors. When this alignment has been completed, the light source is moved into position as shown in Figure 1. The small front surface mirror should be located approximately 77 inches from the parabolic mirror and 1 inch outside of the collimated beam diameter. With the lamp turned on, the pinhole is adjusted at the focal length of the point light source lens distance d, as shown in Figure 1 (approximately 6.5 inches). The proper placement of this pinhole should result in a sharp image of the lamp filament on the plate containing the pinhole. Next, the transit is positioned to indicate a level plane between the center of the first parabolic mirror and the porthole of the tank. The transit is then swung in that reference plane to the light source pinhole and the feet of the light source stand adjusted to place the pinhole in the same reference plane.

With the lamp turned on, the small front surface mirror is adjusted to cast a diverging beam concentric with the outside diameter of the parabolic mirror housing. After opening the covers on both parabolic mirrors, the #1 porthole cover can be installed.

It is imperative to adjust the tilt and rotation of the first parabolic mirror so that the collimated beam is concentric with the scribed circle on the #1 porthole cover. If the beam diameter at the #1 porthole cover is larger or smaller than the scribed circle, the point light source is not at the focal length of the parabolic mirror and an adjustment is essential. When the Schlieren System is properly adjusted, a reference object placed in the collimated beam should cast an exact size image on the cover of the second parabolic mirror. It is necessary to remove the porthole covers to prevent distorted images from occurring.

Once the collimated beam has been established, the #1 porthole cover can be removed and the #2 cover installed. Again, the diameter of the beam should be concentric with and the same size as the scribed reference diameter on the porthole cover. Following this procedure, both porthole covers can be removed and the tilt of the second parabolic mirror adjusted to a level position. It is necessary to rotate the mirror to allow the Dynafax camera to be adjacent to the collimated beam with the pinhole at the focal length 60 inches from the mirror. The beam splitter is installed at a distance d_{11} from the second parabolic mirror approximately 45^o to the converging beam. The height of both the Dynafax and the Hycam is adjusted so as to align the optics of each camera with the reference plane previously established by the transit.

B. Dynafax Camera Alignment

To position the Dynafax Camera properly, it is necessary to manually open the Seikosha Shutter and the Dynafax camera shutter. The pinhole behind the Seikosha shutter is then manually adjusted to the focal point of the second parabolic mirror. The optical selector lever on the Dynafax must be adjusted to allow the incoming light beam to be observed externally from the viewing port on top of the Dynafax. The camera and pinhole must be adjusted to center the incoming beam on the cross-hair of the viewing port lens. When aligned properly and the selector positioned to allow the incoming light beam to pass through the camera lens, an image can be observed on the inside diameter of the drum as viewed by removing the front cover at the base of the Dynafax. This image should be clear, circular, and approximately 3/8 inches in diameter.

C. Hycam Alignment

It is necessary to position the Hycam at the distance d_{10} as shown in Figure 1. The incoming beam is viewed from the external viewing port in the back of the Hycam, and the camera is then adjusted to obtain a sharp, round image large enough in diameter to fill the entire frame. The pinhole is placed at the focal point of the converging beam on the Hycam stand.

The positioning of the exploding wire probe, wave height gauges, and peizoelectric pressure transducer is determined by the particular tests being performed.

D. Firing Sequence Adjustment

The firing sequence and required time delay are monitored by using the storage oscilloscope. The mechanical time constants of the Tektronix Shutter Actuator and Seikosha Shutter are ascertained by making use of a photo diode positioned in a light box behind the Seikosha Shutter.

The diagram and schematic in Figure 6 show the essential components of this monitoring device. It is necessary to connect the electronics as shown. A high intensity light must be placed close enough to the photo-diode so as to give several volts output when the shutter is opened. The shutter exposure is then adjusted to 1/125 second, and the shutter is cocked. The scope trigger must be connected so as to trigger on the +5v signal from the voltage divider (See Figure 5). When the shutter actuator trips the shutter, the output of the photo-diode can be observed on the storage scope. The time relative to the step function displayed on the scope screen should be approximately .008 seconds for a shutter setting of 1/125. This test should be repeated several times to measure the repeatability of the shutter. For example, for a setting of 1/125 second, the Dynaflex speed should be adjusted to expose one revolution of the drum film in .008 sec. (1 rev/.008 sec x $\frac{60 \text{ sec}}{\text{min}}$ = 7500 RPM).

Another signal can be added to the scope display as shown in Figure 5 to indicate the explosion trip time (See Figure 6B for typical output signature). Time, T_o is the time of the initial input to the shutter actuator and to the scope trigger.

The upper trace in Figure 6B shows the time constant of the shutter actuator and shutter exposure time indicated by the step function output of the photo diode. The lower trace indicates the negative pulse signalling the explosion time. The delay time of the Rutherford gate output can be varied by adjusting the time delay switches on the Rutherford to allow sufficient time for the initial explosion to occur just as the shutter is opening.

III. OPERATIONAL SEQUENCE

This section describes the operational sequencial information necessary to perform the exploding wire test with the aforementioned equipment.

A. Initial Preparation

The initial preparation includes a cleansing of the optical mirrors and lenses as well as a water wash down of the tank and filter system. The tank is then filled to the desired level, and diatomacious earth filter powder is added to the filter tank through the trap basket adjacent to the pump. The water is then filtered, as required, to obtain a clear, clean fluid for photographing the explosion. The pump and filter system should be operated continuously during "testing" to prevent the formation of thermal stratification of the water. The filter will require periodic cleaning and flushing of the cloth screens, and renewal of the diatomacious earth. The flushing of the filter is required whenever the tank pressure reads greater than 20 psi.

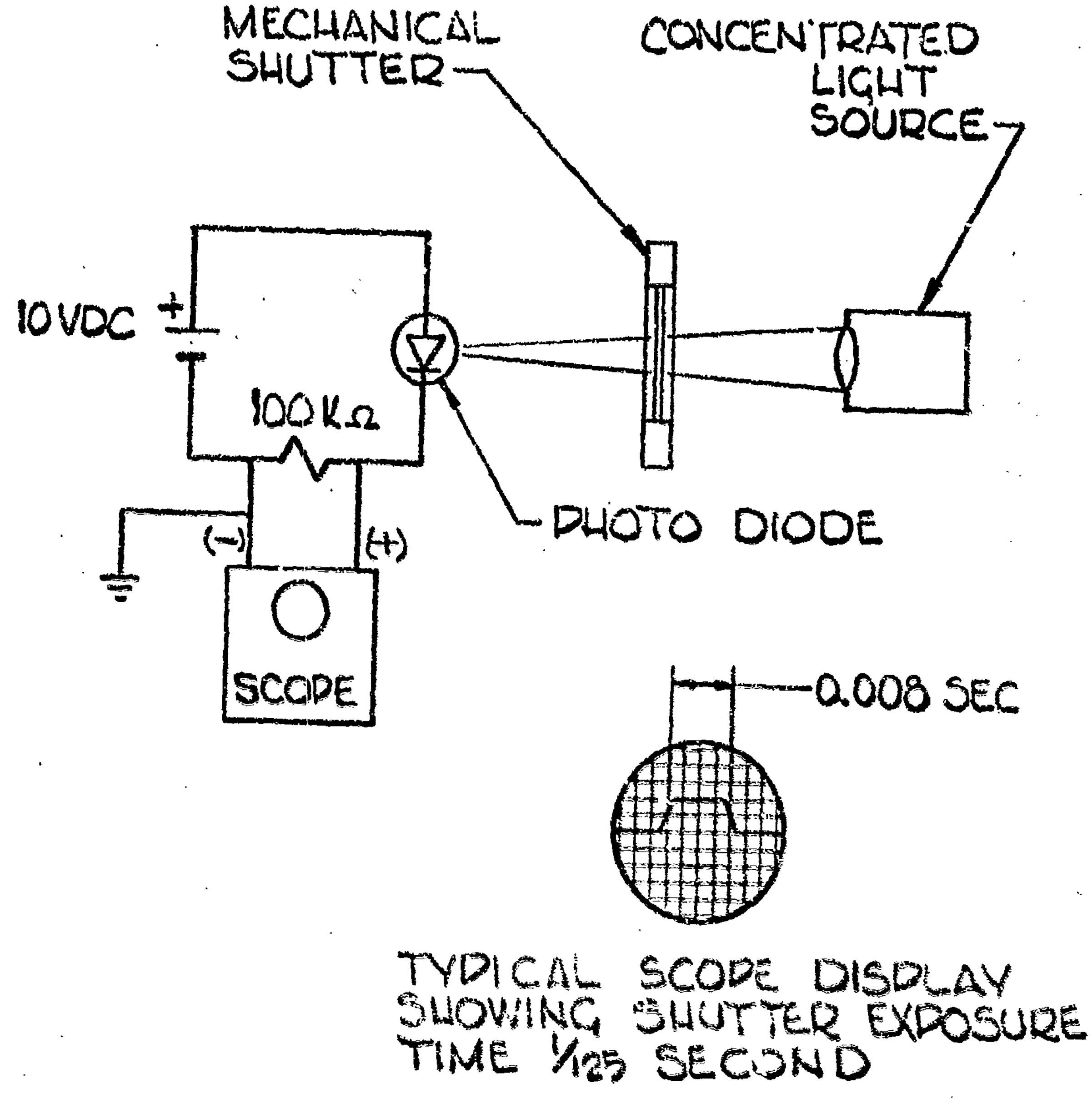
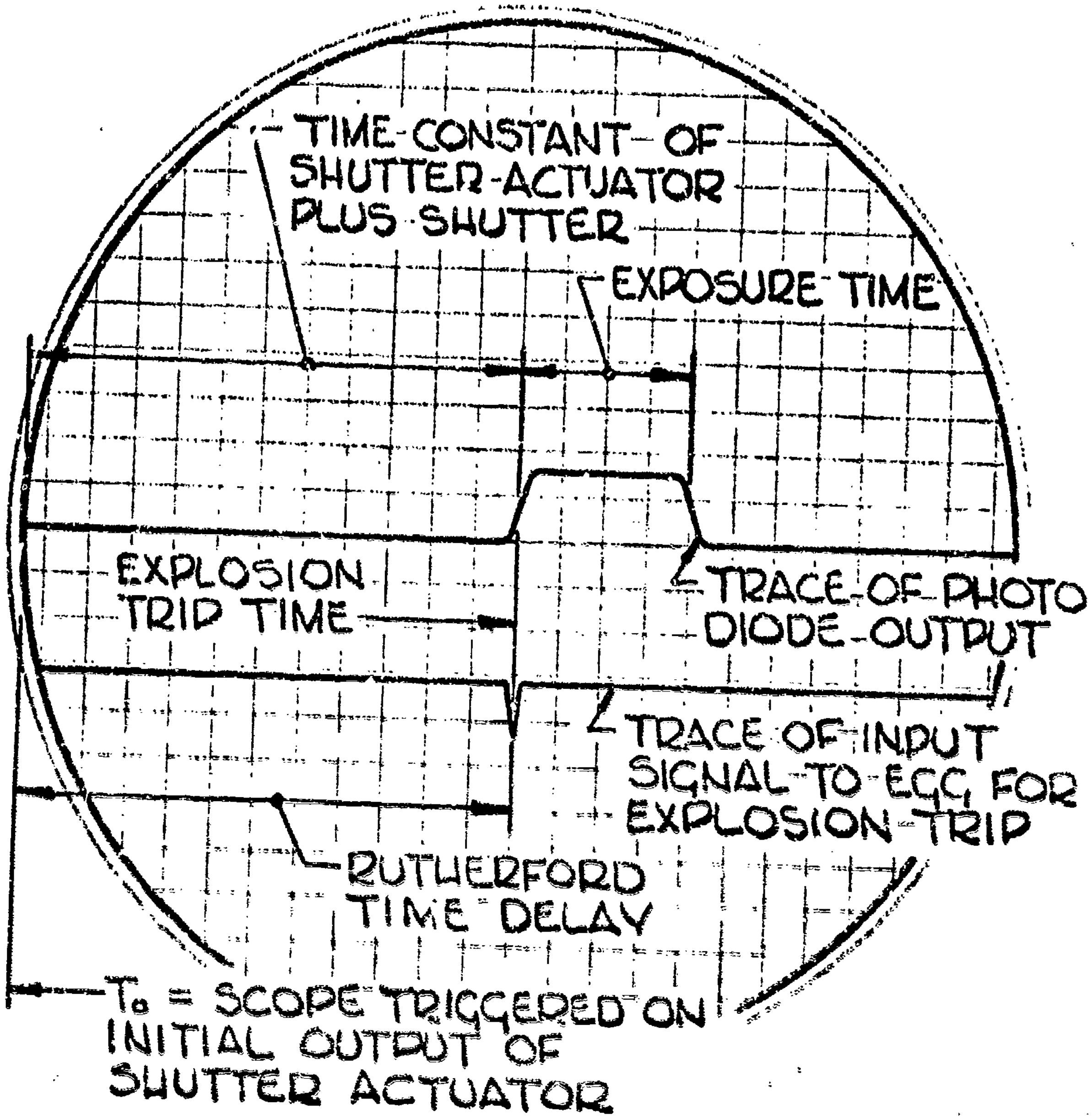


PHOTO DIODE SCHEMATIC FOR ADJUSTING EXPLOSION TIME SEQUENCE

FIG. 6A



TYPICAL SCOPE DISPLAY
FIG. 6B

B. Exploding Wire Probe Preparation

The exploding wire probes are now prepared. An assembly drawing of the probe is shown in Figure 4. The exploding wire filament (#40 nichrome wire) is attached to the leads of the probe by contact welding. The leads should be adjusted to a gap of approximately 1/8 inch. After the filament is welded in place, the resistance of the probe is measured and should be 1 to 2 ohms. Once the filament has been successfully welded, the entire probe is dipped in an acrylic lacquer to insulate the probe filament from the water when it is submerged in the tank. Following this, the probe can be installed in the tank at a desired location. The wave height gauges are positioned and the inside surface of the glass portholes are cleaned. To verify that the probe filament is still intact, the resistance across the brass hemispheres of the trip mechanism is measured. It should be less than 3 ohms.

C. Verify Optical and Electronic Systems

The electrical system must be connected properly as shown in Figure 5. The mercury arc lamp can be turned on and the current set to 5.5 amps. With both parabolic mirror covers opened, the plexiglass porthole covers can then be removed. To verify that the optical system is aligned properly, the light beam must pass through the pinholes of both the Dynafax and Hycam cameras.

With the master firing switch in the "off" position, it is necessary to turn all AC power to the "on" position for the following equipment: oscilloscope, Hycam, Tektronix Shutter Actuator, Rutherford, EGG Microflash, photo diode power supply, Houston Counter, Wave Height Gauges, Redlake Millimite and the capacitor power supply with "charge-discharge" switch in the latter position. The oscilloscope triggering mechanism should be adjusted as follows: mode-trig; slope-neg.; coupling-D.C.; source-Ext. The sweep time of the scope should be 5 milsec/cm, photo diode preamp - 5 volts per/cm (D.C.) and the EGG photo-flash trip preamp 10 volts/cm (D.C.).

The firing sequence can be tested by cocking the shutter and tripping the shutter actuator and the EGG trip mechanism by manually closing the back of the Hycam. With no film in the camera, the camera back plate actuates the relay switch which is set to close after the Hycam has accelerated to constant speed during the normal operation. The storage scope display should appear similar to the signatures shown in Figure 6B. After several tests, it should be verified that the shutter actuator time constant and exposure time are repeatable. The time delay on the Rutherford should be regulated so that the EGG trip pulse is occurring at the same point in time correspondent to the opening of the shutter as shown in Figure 6B.

D. Step-By-Step Firing Procedure

This section lists the step-by-step procedures to be taken for a test explosion.

1. The film is loaded into both cameras and the back of the Hycam is closed.

2. The Seikosha Shutter on the Dynafax Camera is cocked. (The Dynafax shutter must be in the open position.)

3. The capacitor power supply switch is placed in the "charge" position; and the capacitor is charged to 15K volts then the power supply voltage is backed off to zero volts.

4. The Dynafax Camera is turned on, and the camera speed adjusted as required for desired framing rate as indicated by the RPM on the Houston Electronic Counter. (1 rev. = 224 frames); (1 rev. to be exposed in .008 sec. at a Seikosha Shutter setting of 1/125 sec.)

5. The Red Lake Millimite is turned to 1000 flashes/sec.

6. The Hycam power supply is adjusted to 3000 frames/sec.

7. All available data is recorded on a typical data sheet as shown in Figure 7.

8. The wave gauge chart recorder is turned to high speed.

9. The master firing switch is turned to the "on" position.

The above steps conclude one test shot. Immediately [illegible]ing the shot, the Dynafax camera and chart recorder are turned "[illegible] [illegible] capacitor power supply switched to the "discharge" position. The A[illegible] [illegible]uipment must be de-energized, and the film and data retrieved for analysi[illegible]

The information concerning the pressure transducers was not included for test description. These transducers can be connected to an oscilloscope and photographs taken of their signatures for a given test to record explosion yield by measuring shock wave maximum pressures.

IV. SUMMARY

The preceding information is essential is conducting an underwater test explosion as exhibited in the shock test facility presently available at NRL, Washington, D.C. Also included in this operating manual are photographs of the facility and instructional diagrams which have been appropriately labelled. Questions concerning the operation of this test facility can be directed to Cushing Engineering, Inc., Northbrook, Illinois or the writer of this document.

FIGURE 7

TYPICAL DATA SHEET

A. Camera Data

1. Framing Rate of Dynafax Camera ______________
2. Magnetic Pick Up in Pulses/Sec ______________
3. Writing Time (sec) of Dynafax ______________
4. Shutter Setting on Dynafax ______________
5. Record Bolex Camera Framing Rate ______________
6. Record Red Lake Camera Framing Rate ______________
7. Red Lake Mini-Light Setting ______________
8. Red Lake Camera a. aperture b. focus setting a. ______________
   b. ______________
9. Dynafax Camera a. aperture b. focus setting a. ______________
   b. ______________
10. Bolex Camera a. aperture b. focus setting a. ______________
   b. ______________

B. Tank Setting and Dimensions

1. Physical Dimensions

d_1 ______________	d_6 ______________	d_{11} ______________
d_2 ______________	d_7 ______________	d_{12} ______________
d_3 ______________	d_8 ______________	d_{13} ______________
d_4 ______________	d_9 ______________	
d_5 ______________	d_{10} ______________	

2. Probe No. ______________
3. Height or Depth of Probe ______________
4. Resistance of Wire before acrylic coating ______________

5. Resistance of wire after acrylic coating ____________

6. Wire Diameter ____________

7. Wire Length ____________

8. Wave Gauge Distances from Probe ____________

9. Water Temperature ____________

10. Tank Pressure ____________

11. Distance from LC10-1 to probe (pressure transducers) ____________

12. Distance from LC10-2 to probe (pressure transducers) ____________

C. Data Taken at Control Station

1. Measure Capacitance of LC10-1 (pressure transducers) ____________

2. Measure Capacitance of LC10-2 (pressure transducers) ____________

3. Oscilloscope readings - Model No.

   a. Sweep Rate ____________

   b. Volts/Div ____________

   c. Pre-Amp No. ____________

   d. Trigger level ____________

4. Time Delay for LC10 Triggering ____________

5. High Voltage Cable Resistance ____________

6. High Voltage Cable Capacitance ____________

7. High Voltage Capacitor Voltage ____________

8. Sensitivity Setting and Water Level Setting ____________

   a. Wave Gauge No. 1 ____________

   b. Wave Gauge No. 2 ____________

9. Recorder Speed (for Wave Gauge Record) ____________

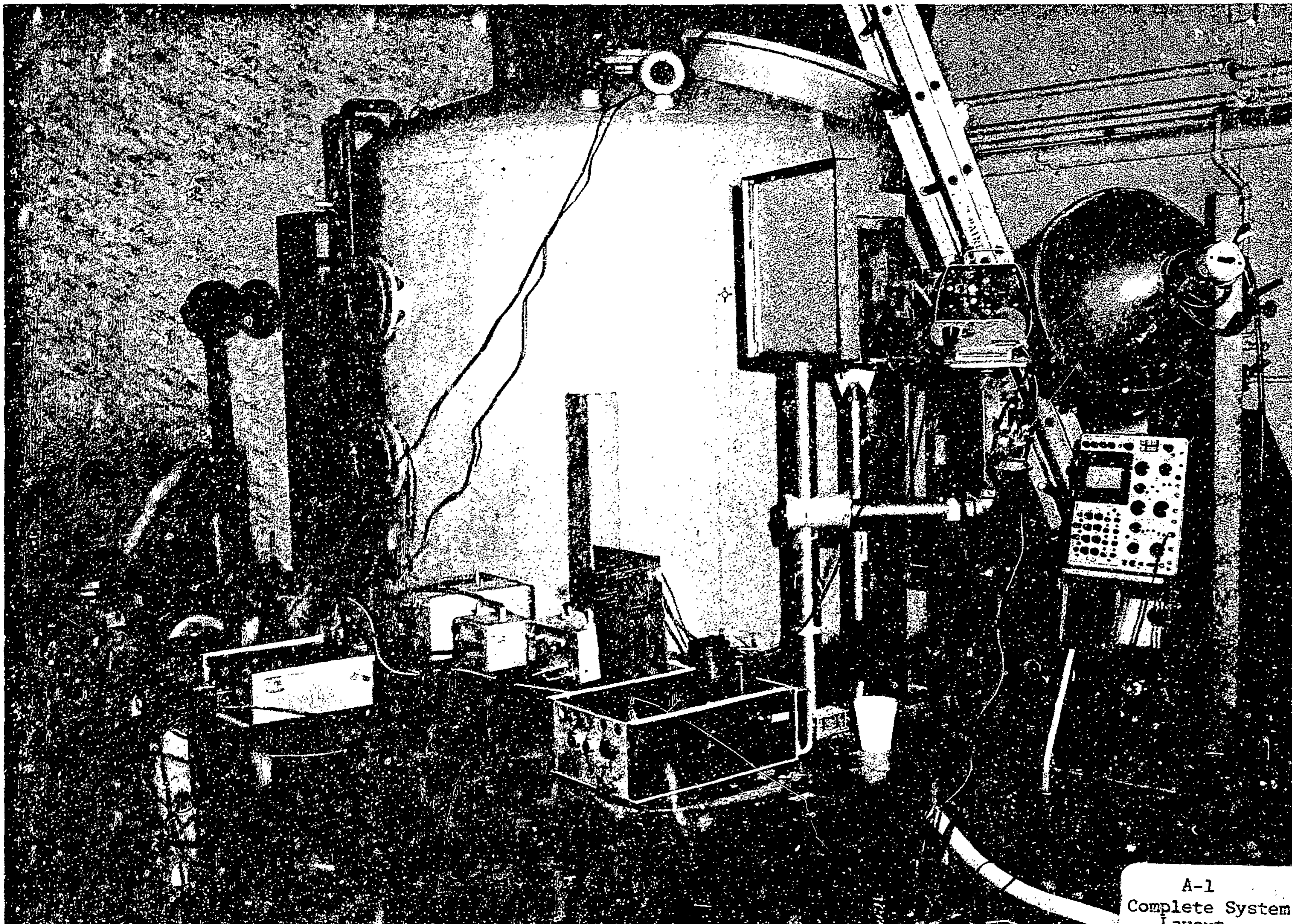
10. Recorder Setting (volts/cm) ____________

11. Voltage on Discharge Capacitor ____________

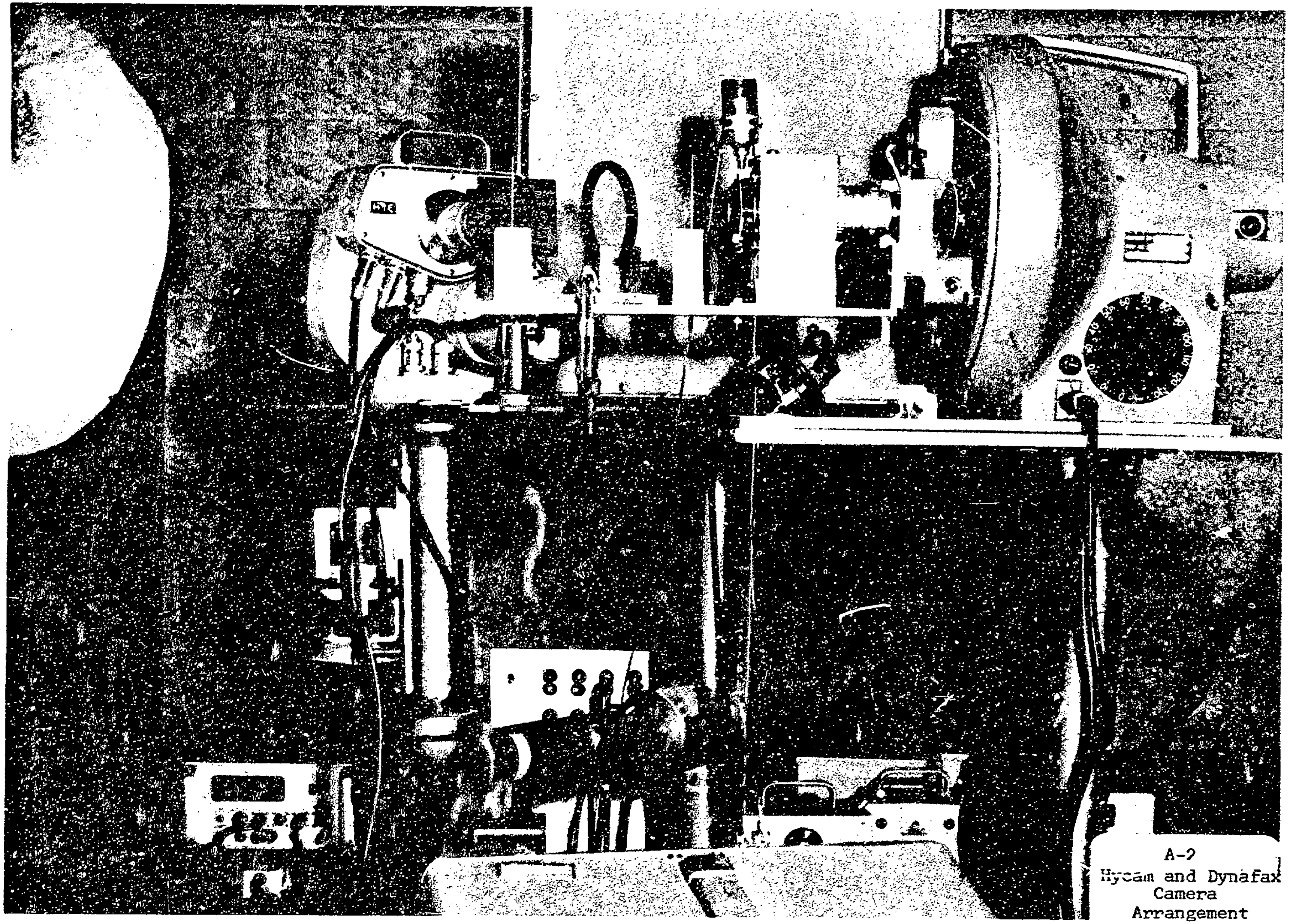
APPENDICES

APPENDIX A

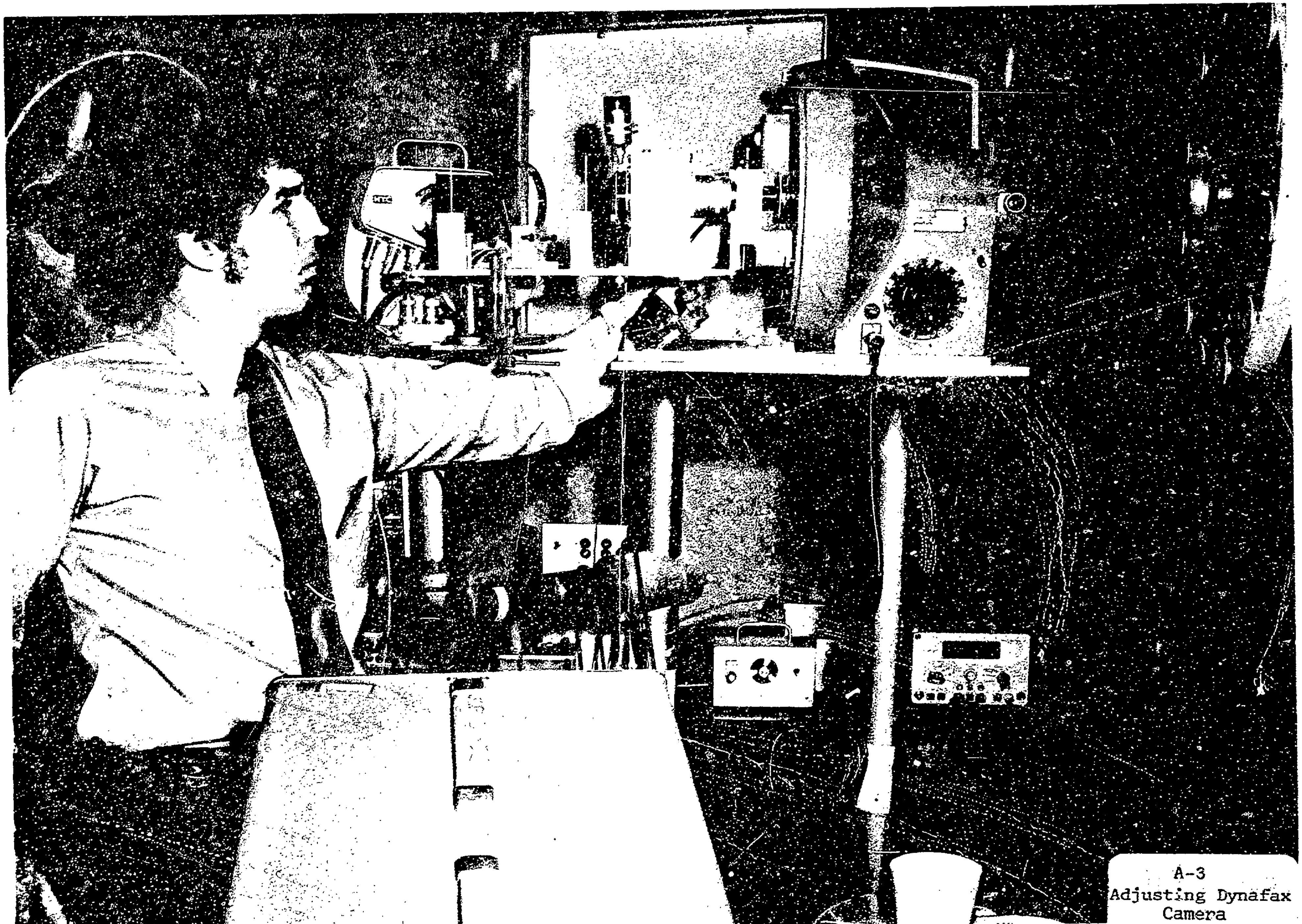
PHOTOGRAPHS



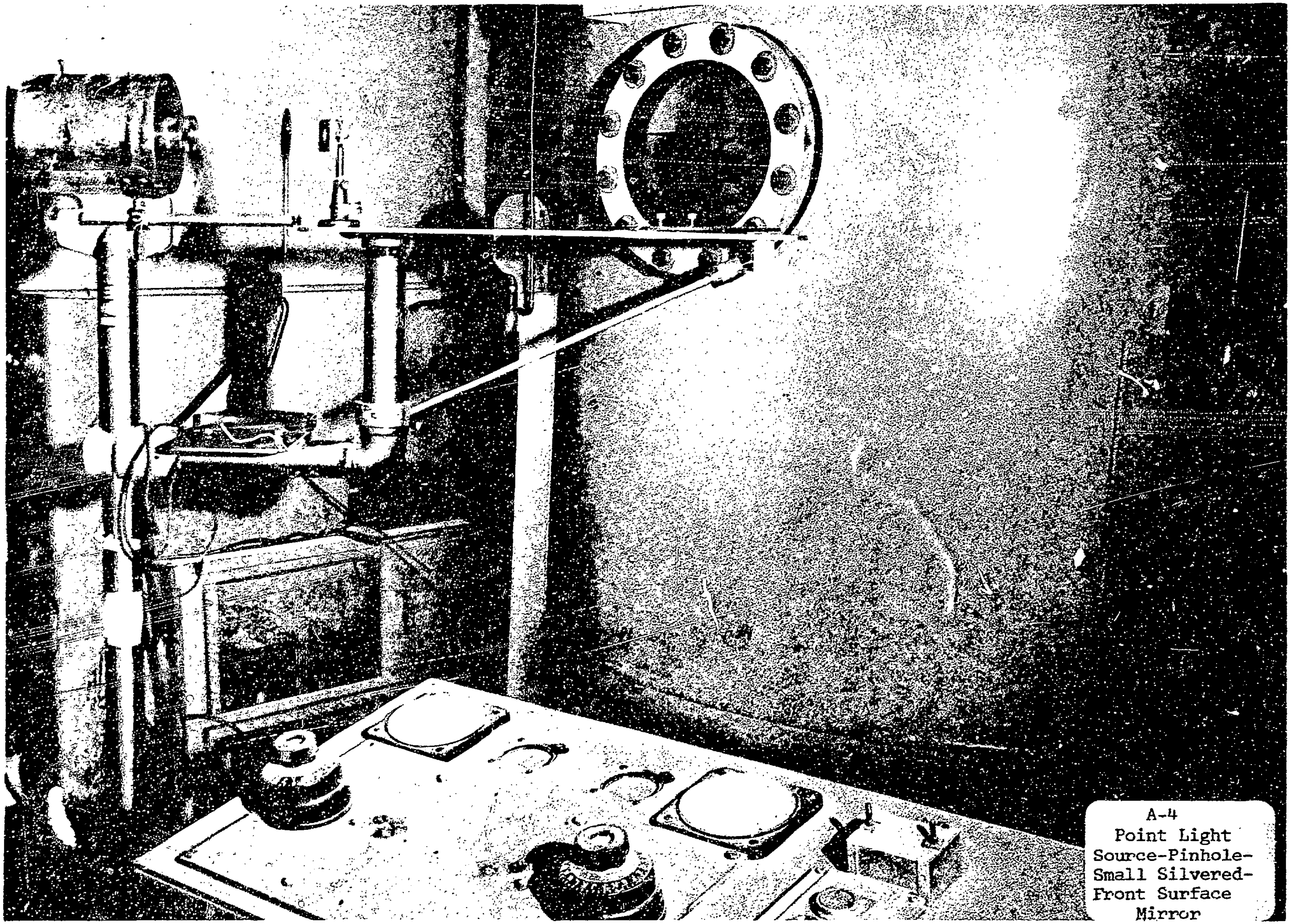
A-1
Complete System
Layout



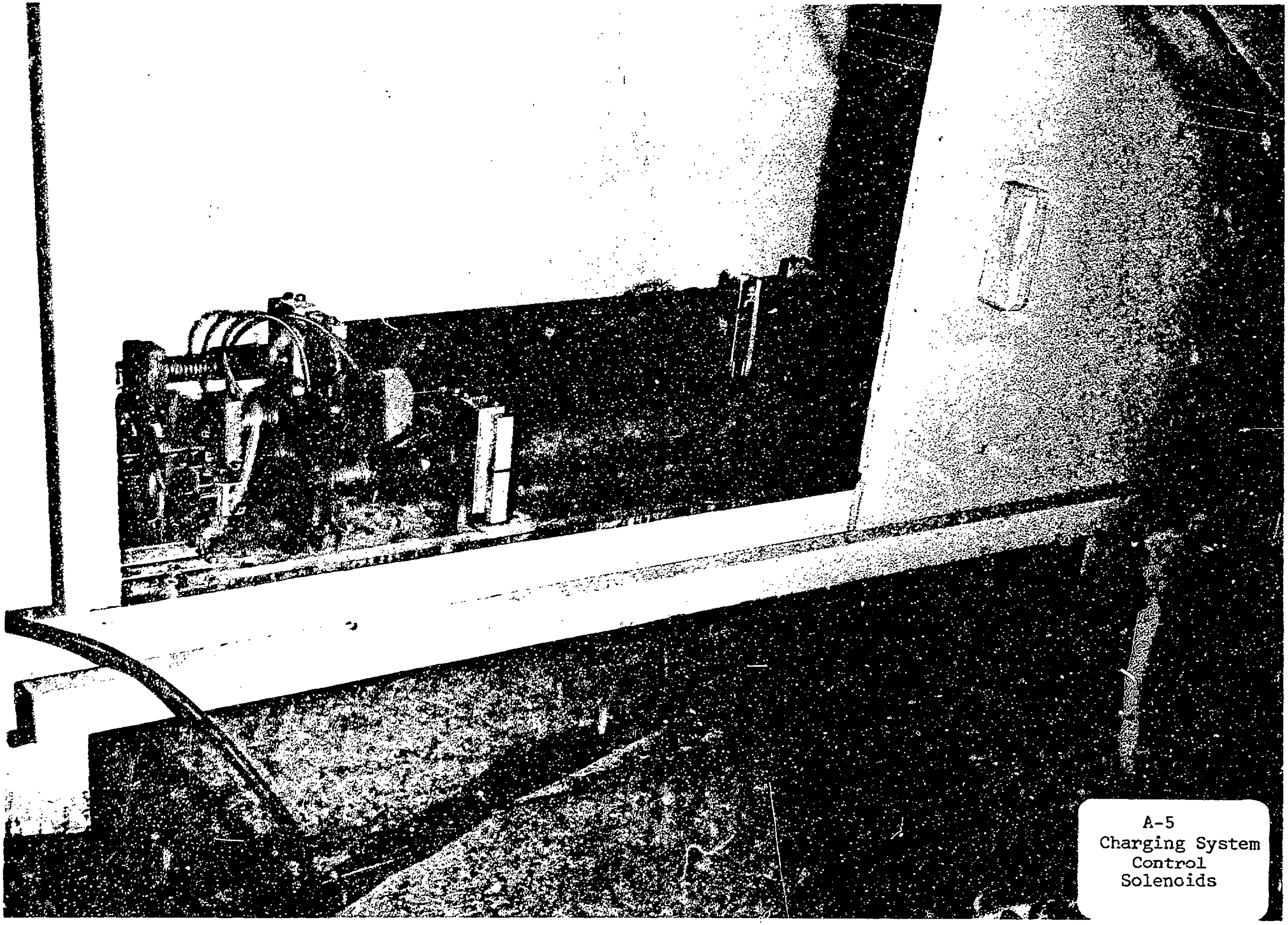
A-2
Hycam and Dynafax
Camera
Arrangement



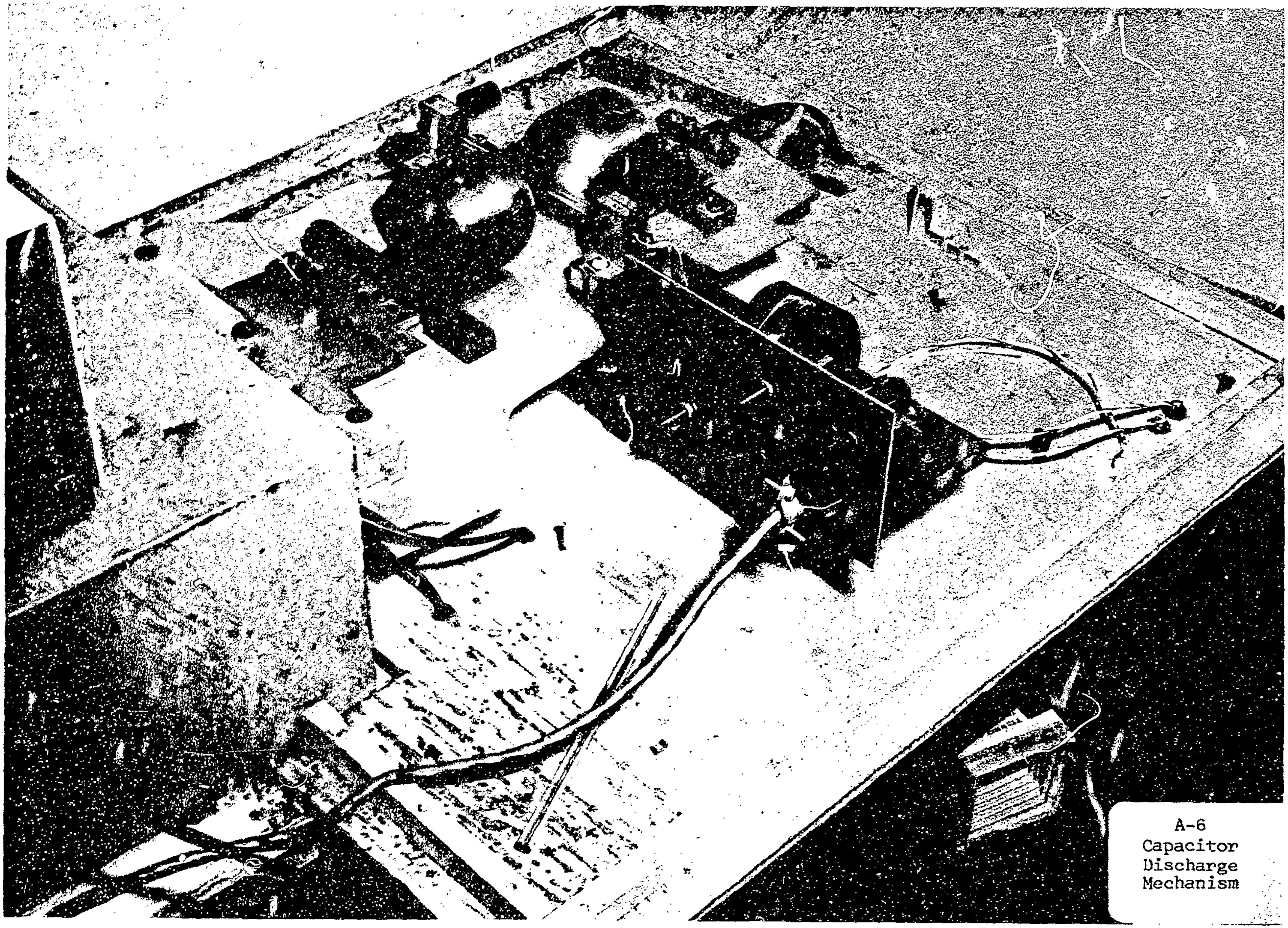
A-3
Adjusting Dynafax
Camera



A-4
Point Light
Source-Pinhole-
Small Silvered-
Front Surface
Mirror



A-5
Charging System
Control
Solenoids



A-6
Capacitor
Discharge
Mechanism

APPENDIX B

PERSONNEL RELATING TO SHOCK TEST EXPERIMENTATION IN WASHINGTON AREA

The following persons were contacted in an attempt to identify a user for the test facility presently located at Naval Research Lab, Washington, D.C.: (Responses were negative.)

Naval Ordnance Lab (New Hampshire Avenue)
Mr. Robert M. Barash 301-394-2583

Naval Ship Engineering Center (Hyattsville)
Code 6105G Hanley Ward 436-1982
Code 6153 John Conway 436-1248

Naval Ship Research and Development Center (Carderock)
Dr. W. Murray 227-1705
Dr. Short 227-1726

Underwater Explosion Research and Development Center (Norfolk Naval Shipyard)
Dr. E. Palmer 804-393-5098

APPENDIX C

LIST OF EQUIPMENT MANUALS AVAILABLE

1. EG&G 549 Microflash System, Number B-3114, 15 July, 1965.

2. Houston Instrument Corporation, Transistorized Timer Counter TC2A

3. Rutherford Electronics Company, Model All Digital Time Delay Generator

4. Tektronix Shutter Actuator, 1962.

5. Tektronix Storage Oscilloscope Type 549, and others.

6. Red Lake (HYCAM) Millimite Flash and Dynafax Camera manuals are available at the Cordin Company, Salt Lake City, Utah, 801-487-1075 (Also Red Lake Lab, Santa Clara, California).