

245727

DP-MS-83-95

A PYROVIDICON-BASED INSPECTION SYSTEM FOR
NUCLEAR REACTOR SAFETY

by

Edwin C. Lynam
E. I. du Pont de Nemours & Co.
Engineering Dept.
Wilmington, Dela. 19898

Proposed for presentation at the annual
Conference of the Society of Photo-Optical Instrumentation
Engineers
October 2-5, 1983
and publication in the proceedings

SRL 1111
RECORD COPY

This paper was prepared in connection with work done under
Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.
By acceptance of this paper, the publisher and/or recipient
acknowledges the U.S. Government's right to retain a nonexclusive,
royalty-free license in and to any copyright covering this paper,
along with the right to reproduce and to authorize others to
reproduce all or part of the copyrighted paper.

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available for sale to the public, in paper, from: U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, phone: (800) 553-6847, fax: (703) 605-6900, email: orders@ntis.fedworld.gov online ordering: <http://www.ntis.gov/ordering.htm>

Available electronically at <http://www.doe.gov/bridge>

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from: U.S. Department of Energy, Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831-0062, phone: (865) 576-8401, fax: (865) 576-5728, email: reports@adonis.osti.gov

**A PYROVIDICON-BASED INSPECTION SYSTEM FOR
NUCLEAR REACTOR SAFETY***

by

Edwin C. Lynam
E. I. du Pont de Nemours & Co.
Engineering Dept.
Wilmington, Dela. 19898

ABSTRACT

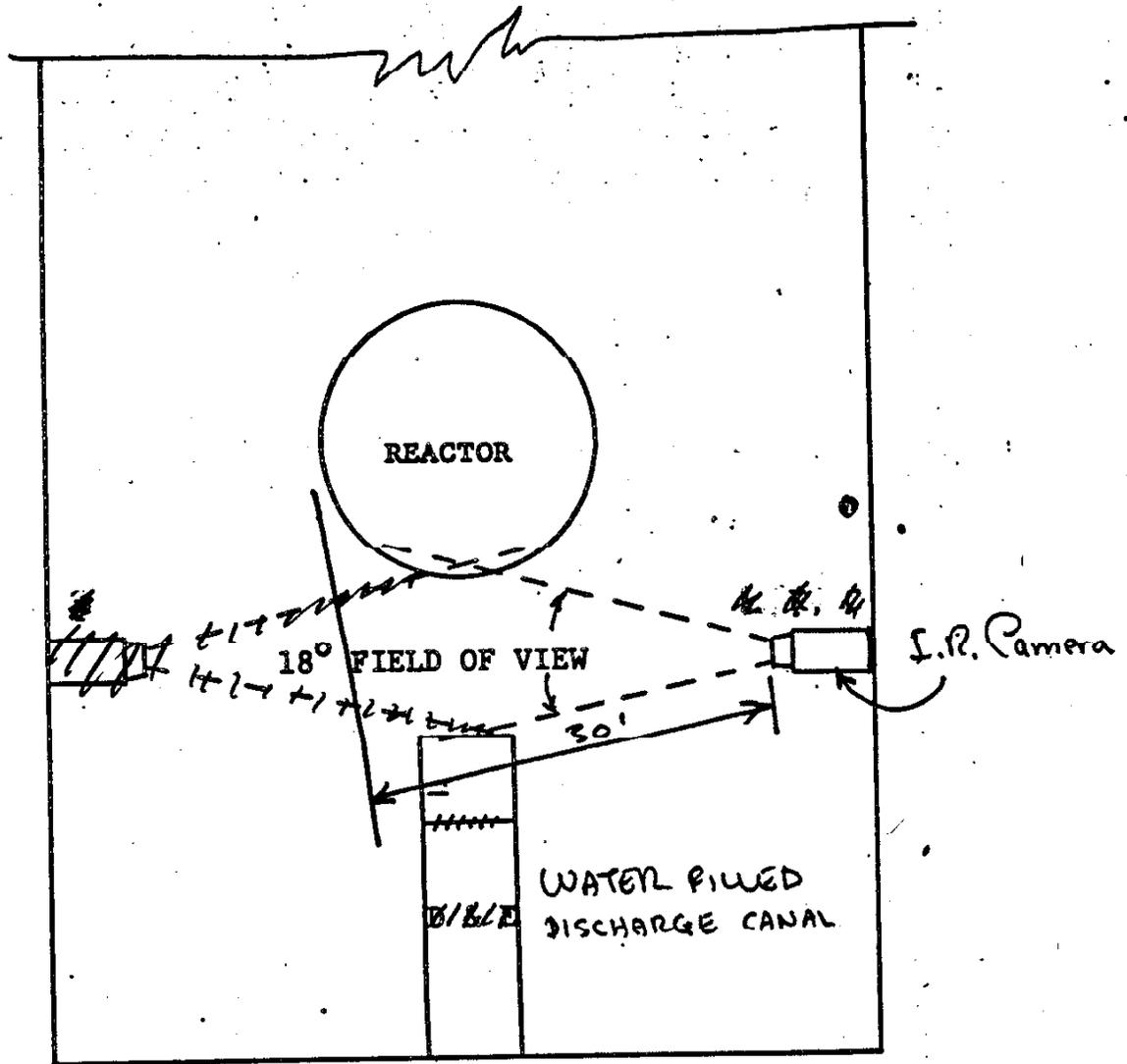
At the Savannah River Nuclear Facility, irradiated assemblies are conveyed through the air from the reactor to a discharge/entry channel, where they are immersed in water. This paper addresses the monitoring of the temperature of these assemblies while they are in transit during the discharge cycle.

To accomplish this, a remotely controlled and monitored, radiation-hardened thermal imaging and alarm system was installed at each reactor.

The paper will discuss the system concept and operation. The program for radiation hardening and testing this equipment will be reviewed.

* The information contained in this article was developed during the course of work under Contract DE-AC09-76SR00001 with the U.S. Department of Energy.

PLAN
PROCESS ROOM LOCATION



PLAN VIEW

FIG. 1

INTRODUCTION

A commercially available pyroelectric vidicon system was adapted for use in a radiation area of the Department of Energy's Savannah River Nuclear Facility. This paper addresses the use expected to be made of this equipment, changes required to enhance its radiation tolerance and the results of the radiation testing.

ROUGH DRAFT

PYROELECTRIC VIDICON BASED INSPECTION SYSTEM
FOR NUCLEAR REACTOR SAFETY

DESCRIPTION

This paper describes a somewhat unique application of a pyroelectric vidicon based Infrared television system. This system is being presently installed at the Department of Energy's nuclear facility at the Savannah River Plant in South Carolina. It will be used to monitor the temperature of irradiated assemblies and components during their discharge from a nuclear reactor.

A little background may be in order first. The Du Pont Company, my employer, designed and built the Savannah River Plant under a nonprofit contract for the US Government in the early 1950's. We still maintain and operate this facility for the Department of Energy.

The reactors at this site are moderated and cooled with heavy water and generate no steam or electrical power. Their use is solely to produce strategic nuclear material. These reactors serve a different purpose than the power reactors later developed for commercial purposes, and there are few similarities. One of the major differences that exist is that the SRP reactors operate essentially at atmospheric pressure and consequently at comparatively low temperatures. These reactors are also designed to be frequently harvested for their radioactive product. The way this is accomplished is through the use of charge and discharge machines that move into the reactor room only when this operation is to take place. The operation consists of the various rods being withdrawn, one at a time, from the reactor by the discharge machine and being carried a distance of

approximately forty feet through the air, to a point where they are lowered into a water filled canal to be conveyed by another mechanism to a water filled storage basin for later disposition (See Figure 1.) The charge machine complements this action by obtaining a new unirradiated rod that is presented to it through a slot in the thick concrete shield wall. This rod is inserted into the reactor in the hole made available by the removal of the irradiated rod. Only the rod being removed is heat generating. This heat is a consequence of its being highly radioactive due to neutron bombardment while in the reactor. There are multiple facilities on the discharge machine to allow the application of cooling water to the heat generating rod as it is being transported, if the need arises.

In the course of our work at this Plant, we were requested to develop a means to remotely monitor the temperature of the assemblies during that period of time they are suspended in air. This was to give additional monitoring capability for this operation. The cooling requirements are carefully calculated and checked for all the assemblies and components discharged from the reactor and this operation is visually monitored through a 4-foot thick leaded glass window.

Our first consideration was to use a conventional infrared camera which would require the use of liquid nitrogen for the cryogenic cooling of its sensor. It became apparent, however, that this requirement would present some nitrogen handling problems since personnel access to the reactor room is not possible during the time an irradiated rod is out of the reactor. Because of this constraint we decided to investigate other methods that might be used to accomplish our purpose.

We hoped to find a system that didn't require cryogenic cooling and would be capable of monitoring the surface temperature of an assembly from a distance of approximately 30 feet (See Fig. 1). The system had to be capable of measuring assembly temperatures ranging between 50°C and 550°C within $\pm 20^\circ\text{C}$ at the upper end. The method used could not interfere with the discharge operation or increase the risk of damage to the assemblies. Another goal was that the system should be reliable for a period of at least 5 years while accumulating as much as 10^6 total rads of gamma radiation.

During our investigation we looked into the possible use of a pyroelectric vidicon. This method uses equipment that does not require the use of liquid nitrogen but has the disadvantage of not presenting temperatures in absolute terms. It also required either periodic blanking of the sensor or relative motion between the camera and the target to maintain the thermographic image on the CRT. We felt that this problem of the fading of a static image could be overcome with the use of a shutter type chopper device mounted on the camera. On investigation we determined that the requirement for absolute temperature readings could be waived so long as we were able to monitor two specific temperature alarm settings.

We contacted a vendor of Pyroelectric video equipment featuring profile generators which provide controllable cursors on the monitor allowing temperature settings to be viewed and alarmed (See Fig. 2). This equipment also had an electro-mechanical chopper which allowed the viewing of a static scene without the fading of the picture. Although it was designed to give an indication of the

relative temperature between objects, we sought to develop a method to calibrate the two setpoint cursors to specific temperatures. These features allow us to have a system that does not require the use of liquid nitrogen yet gives us our monitoring capability.

The needed calibration method was developed by putting together a 1300 watt, 120 volt stainless steel sheathed cartridge heater, with an RTD sensor, which was controlled by a three mode temperature controller (See Illustration 1). Our design locates the heater in the process room in a position where it will present the same apparent length and width as the target when viewed on the monitor. We plan to calibrate against this device to set the position of the alarm point cursor (See Figure 2).

Before we firmed up our final design, we evaluated some different approaches to the radiation hardening of this equipment. I will briefly describe a few of these which, while many were not all have been utilized, may still be of interest for their approach to the radiation hardening of electronic equipment.

The CCTV industry produces cameras for use in radiation areas and has developed several hardening methods that we also considered for our infrared system.

These methods are familiar to us since on another part of our overall project, we are installing a closed circuit TV system with radiation tolerant cameras located throughout the reactor room. Monitors in the control room will allow the operators to observe the charge, discharge operation. Manufacturers of CCTV equipment which is designed for use in radiation areas, use either of two

basic methods to radiation harden their equipment. One method is to select electronic components for use in their system that are inherently resistant to the effects of radiation and utilize them in circuits whose characteristics can tolerate some of the deleterious effects of the radiation. The other method is to use more conventional components but to locate as much of the circuitry outside the radiation area as possible. This method, however, results in the requirement for more wiring between the camera inside the radiation area and the remote circuitry outside. The vendor we had chosen for the CCTV system uses this second method. Our CCTV and pyroelectric vendors agreed to evaluate the pyroelectric equipment to see if this same hardening technique could be applied. The CCTV vendor had some previous experience with pyroelectric equipment and felt they could repackage this pyroelectric video equipment and integrate it into their hardened CCTV system.

Upon investigation, however, the technique they used to harden their own equipment was not easily transferred to the pyroelectric equipment and we felt that the result of this work on the infrared system performance would be uncertain.

From recent experience with radiation testing we had been conducting on other electronic equipment, to be used in the same environment, we knew of still another radiation hardening technique that we could apply. This method was also considered but not used. It involved the replacement of all the 4000 Series CMOS IC's on the vendors synch and pole generator circuit board with special radiation hardened CMOS chips which are available from certain chip manufacturers. Hardened chips are specially manufactured by these

companies and are available at premium cost but not all IC's are available in this form. Most of those manufactured are used by the military, and we have found them difficult to obtain in small lots. At the time our program was taking place, direct replacement of all the chips in the circuit was not possible, due to some not having hardened counterparts. Had we used this chip replacement method we could reasonably have expected to have increased the total dose failure threshold of the circuit board from the expected 10^3 - 10^4 rads with the use of regular CMOS chips to above 10^5 rads with the use of hardened chips.

A third technique for hardening is to utilize TTL circuits instead of CMOS. TTL circuits are intrinsically more radiation tolerant than CMOS and we could realistically expect to get at least an order of magnitude improvement in hardness with their use versus the normal CMOS chips.

We also have had proven success with the use of lead shielding to protect against radiation.

It was a combination of these last two methods that was chosen to radiation harden our equipment.

By using TTL circuitry and lead shielding we were confident we could make this equipment suitable for our use. The pyroelectric vidicon vendor, at our request, redesigned his synch and pole generator circuit board to use TTL circuitry in place of the CMOS utilized in his original design.

We specified that the camera be enclosed in a heavy environmental enclosure with a 1-1/4" thick lead belt around that portion of the

enclosure covering the electronics of the camera and the lens. The infrared vendor also coordinated his design with the CCTV manufacturer to make his panel fully compatible with the CCTV vendors system so that it could be housed in their cabinet. When this equipment was fabricated and functionally proven, we went into the radiation testing phase. Illustrations 2 through 6 show the equipment in the vendors shop.

We took our equipment to a gamma radiation facility at the Department of Energy's Sandia National Laboratory in Albuquerque, New Mexico and utilized one of their radiation cells for the test (See Illustration 7). This cell has a Cobalt 60 radiation source with a reactivity of approximately 100 kilocuries at a gamma energy of 1.33 MeV. This capacity was sufficient to expose our equipment to a maximum dose rate of $2.8(10^3)$ rads per second in Silicon. (See Illustration 7) We had designed the lead belt over the environmental enclosure to abate the radioactivity by one order of magnitude. To get the maximum amount of radiation exposure on the camera, however, we tested the camera without this enclosure or the shielding.

We attached dosimeters directly on our camera, placed it inside the cell and exposed it to the radiation while it was transmitting a picture to a monitor located outside the cell (See Fig. 3). We monitored the signal at grid one (G1) of the vidicon and also put the composite video signal on our scope which allowed us to monitor the overall performance of the video amplifier. (See Fig. 4)

We videotaped the output of the camera throughout the test for later review and evaluation. We knew from previous experience that

radiation effects are cumulative and that electronic degradation increases gradually until it finally reaches a point where it avalanches to total system failure.

Upon reaching our test goal by accumulating over 10^5 rads, the camera was still performing within specification. The only deleterious effect was a decrease in the gain of a transistor in the video amplifier that mixes the synch and video signal. This effect was minimal however, and would not be significant in actual operation. This component has been targeted for close operational scrutiny however, and is a candidate for periodic replacement. The brightness of the picture gradually increased as the radiation accumulated, but this effect was not objectionable as it would also be spread out over a long period of time. The use of the brightness control adjustment will effectively compensate for this drift.

Prior to this test, there was very little information available concerning the effects of ionizing radiation on Germanium as it is used for the lens of an infrared camera. The lens received 10^6 rads during the test and we observed no effect on the picture due to the irradiation of the lens. A transmission test performed on the lens afterward confirmed that the lens had not been adversely affected by the radiation since it showed no change from its original characteristics.

At the conclusion of our test we had accumulated from $3(10^5)$ to (10^6) rads on various parts on the camera and it still operated within specification (See Figure 5). When the shielding is added, increasing the tolerance of the system by another order of magnitude, it will have met its five year anticipated use goal.

I have described some of the techniques that may be used to radiation harden electronic equipment beyond its normal expected capability. We used a combination of two of these methods to successfully adapt a commercially available system to our unique conditions and use. Any of these hardening methods may be used on electronic systems which must be adapted for use in radiation areas. The proof of any such systems operation prior to its actual use still lies in its being thoroughly tested. Another important factor for success is having the cooperation of vendors willing to adapt their designs as necessary and who are committed to being involved all the way through the testing phase. The vendors who worked with us to adapt our equipment operated in this manner and as a consequence we have developed a system that will make a significant contribution to the operation of our facility.

SUMMARY

The results of the functional and radioactive testing of this equipment indicate that it will perform satisfactorily in our installation.

VIDEO OUTPUT SCREEN

MOVABLE
ALARM

POINT
CURSOR

MOVABLE
ALARM

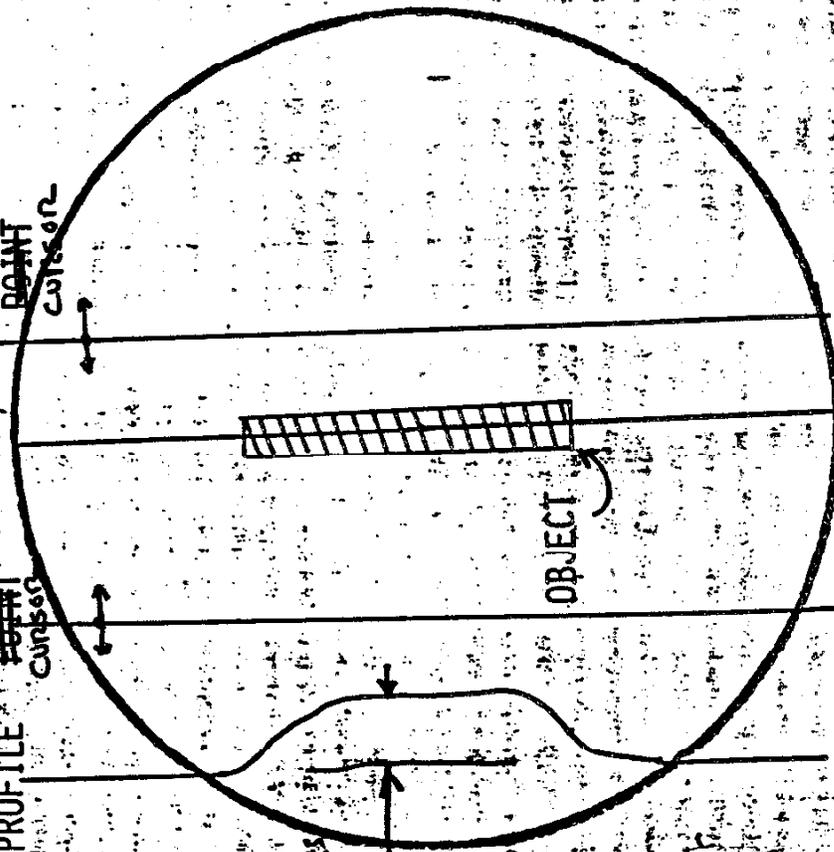
POINT
CURSOR

TEMP.

PROFILE

CURSOR

Amplitude increases
with temperature
of object viewed

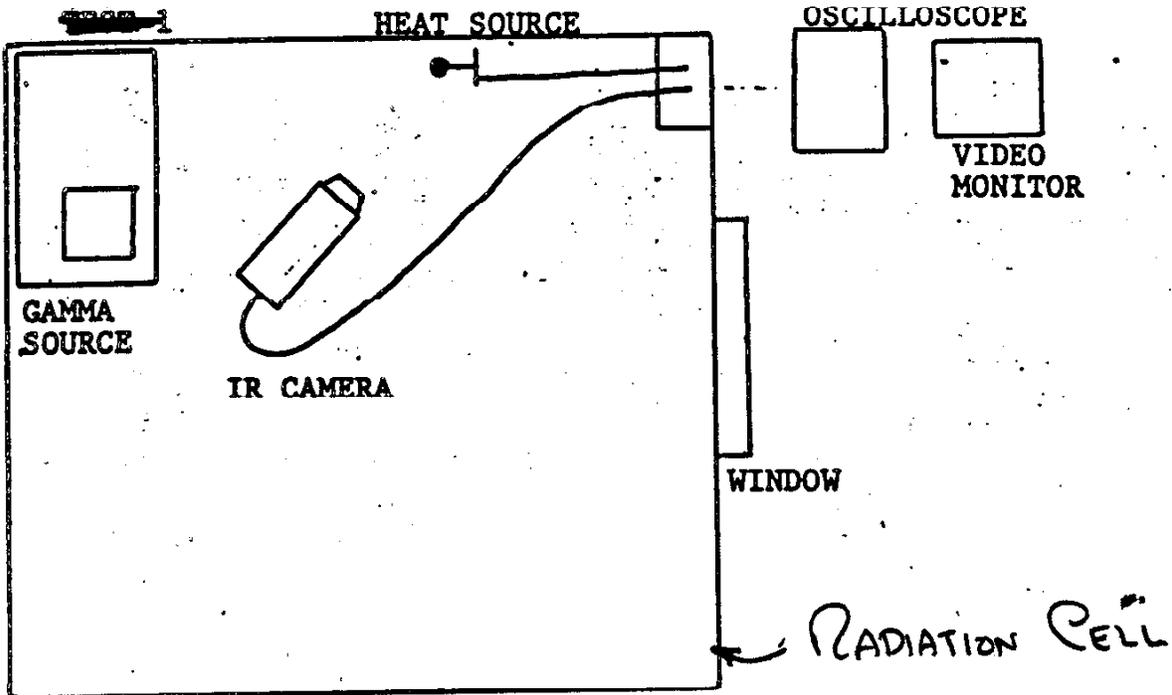


Note: If profile cursor
touches the alarm
cursor an alarm
is sounded.

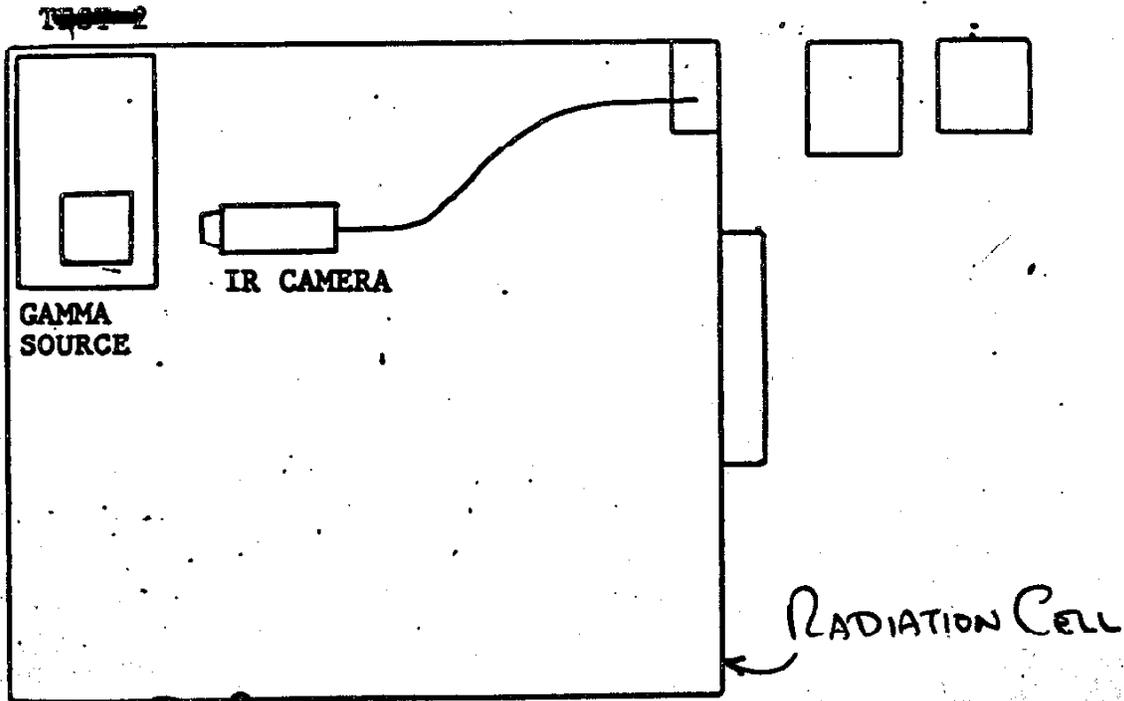
CENTER LINE
CURSOR

FIG. 2

GAMMA RADIATION TESTS

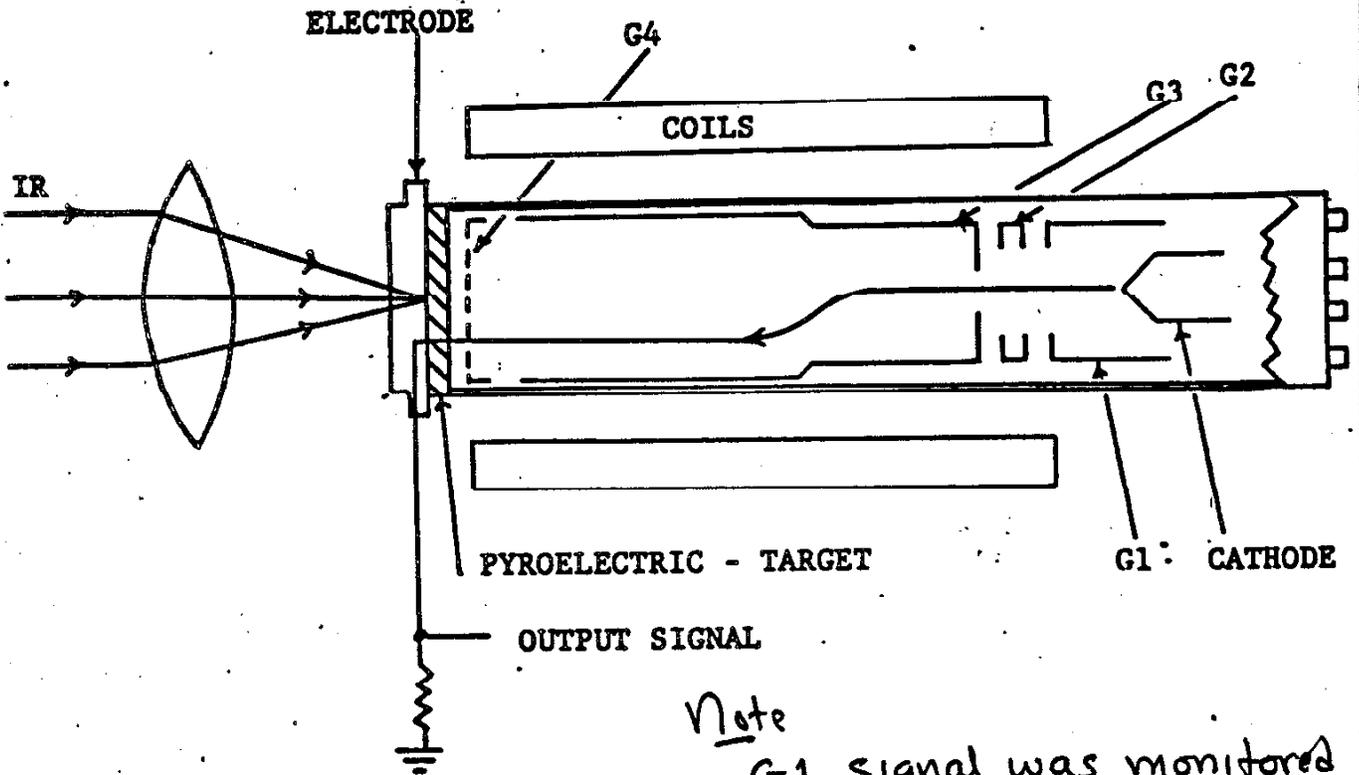


Test Configuration # 1



Test Configuration # 2

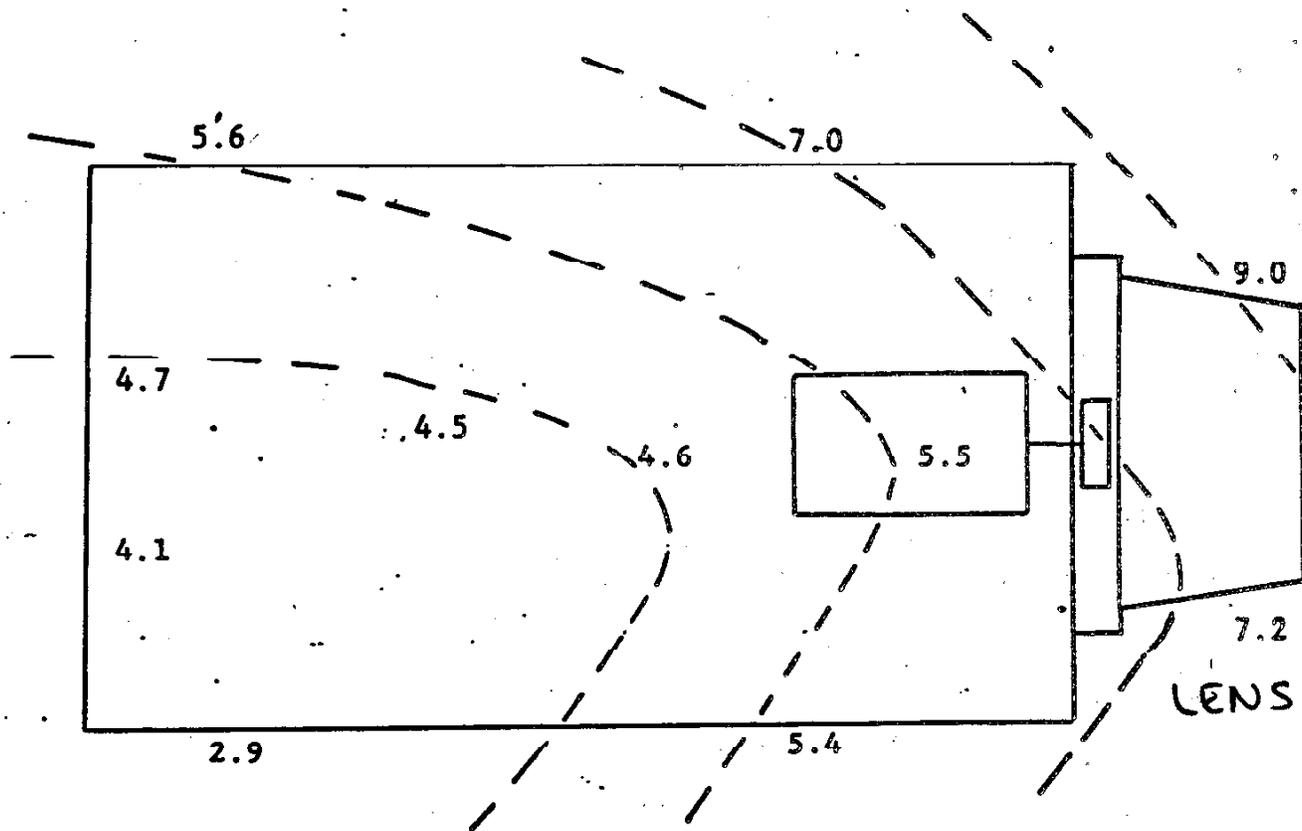
PYROELECTRIC - TARGET VIDICON TUBE



Note
G1 signal was monitored during the radiation testing.

FIG. 4

RADIATION ACCUMULATIVE EXPOSURE (10^5) RADS



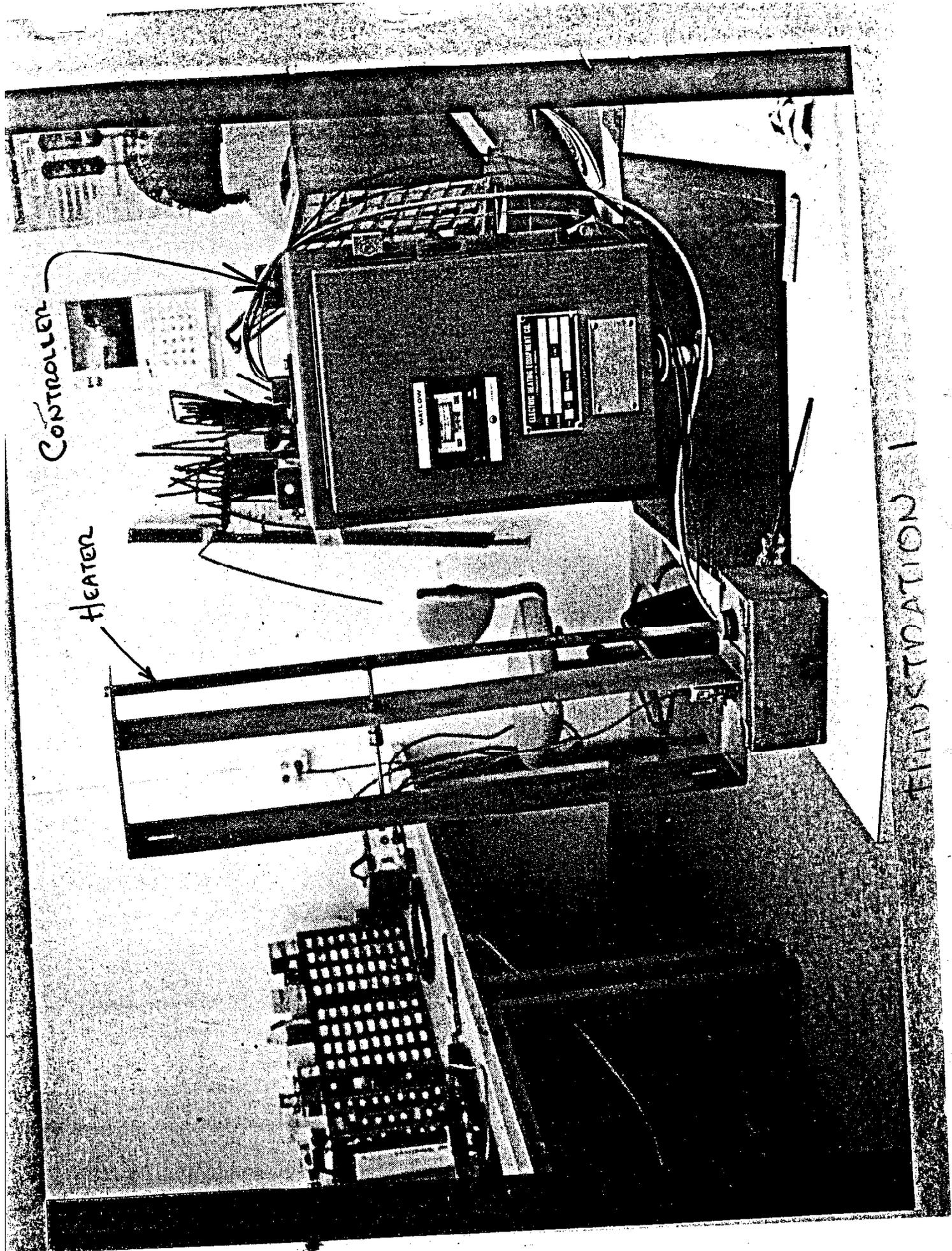
CAMERA TOP VIEW

FIG. 5

CONTROLLER

HEATER

FLUORINATION 1



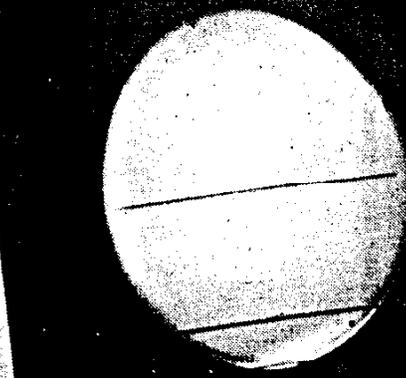
Camera Control Panel which mounts
in CCTV Cabinet.



ORDER NO. LIC-4568
ENG. NO. P34-465-60



SALES INDUSTRIES INC.



TELEVISION
PUSH ON
CONTRAST
BRIGHTNESS
HOLD
HOLD
WIDTH
HOLD



REFERENCE 1
REFERENCE 2

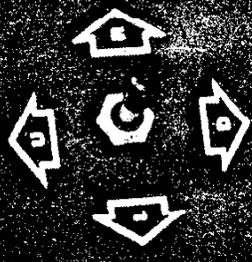
PROFILE GENERATOR

NEAR
FAR

REMOTE LENS FOCUS

ON
OFF
RIGHT
LEFT

CHOPPER



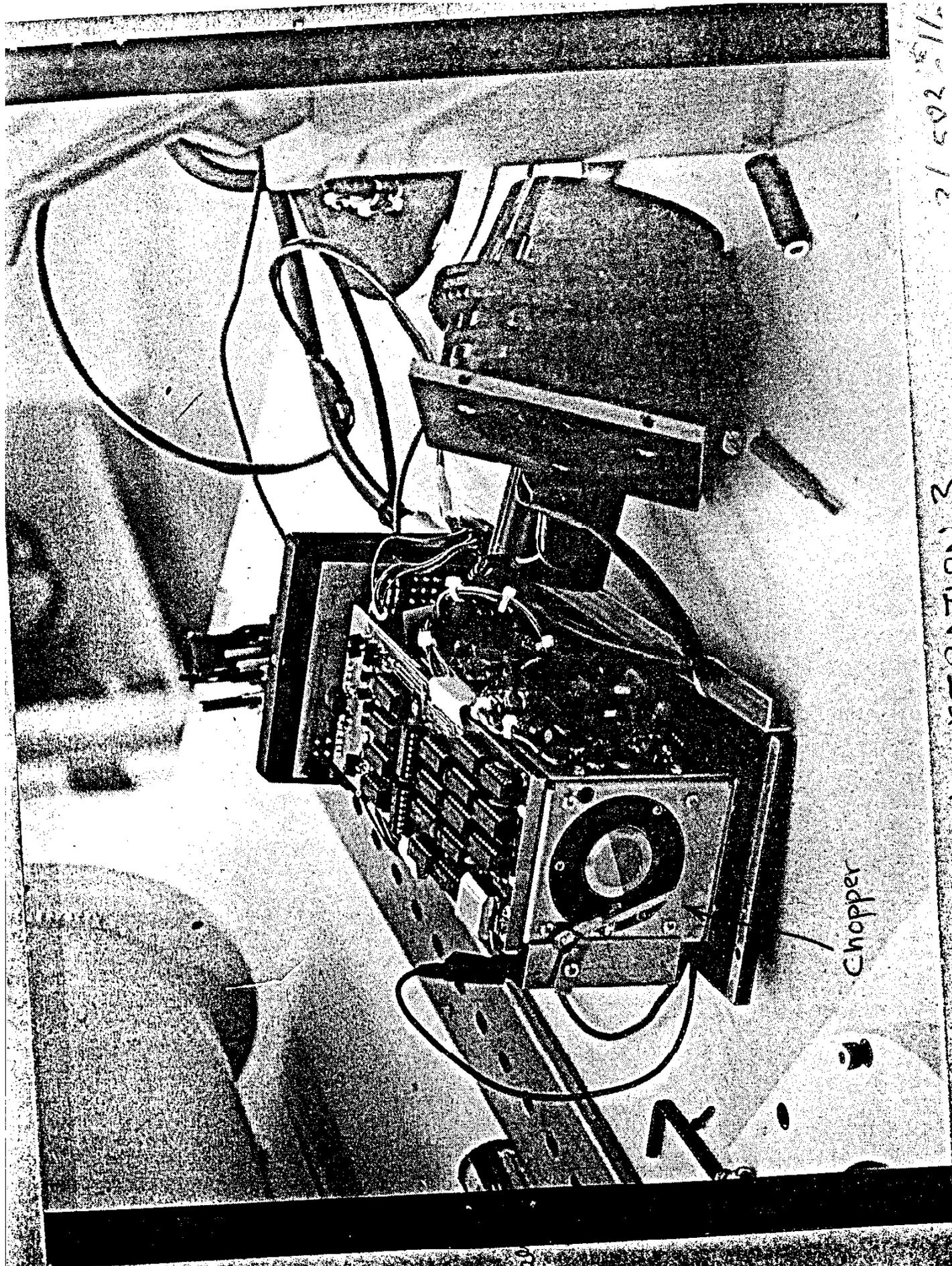
PAN AND TILT
PUSH ON

CALIBRATOR

SALES INDUSTRIES INC.
PRODUCTION SYSTEMS
1000 W. 10th St., Suite 101
Orem, Utah 84057
Phone: 714-329-2176



ILLUSTRATION 7

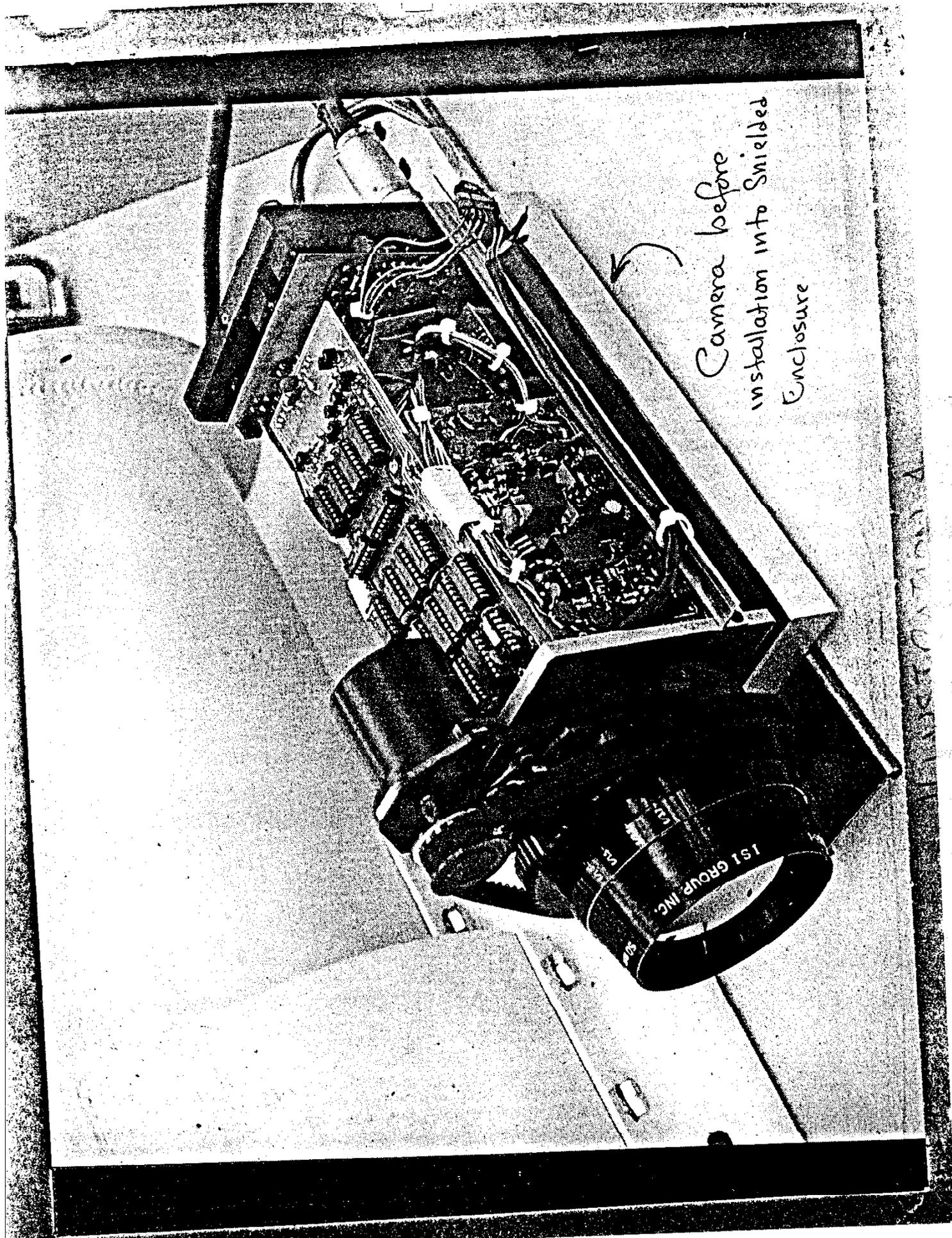


21 502 16

ILLUSTRATION 3

Chopper

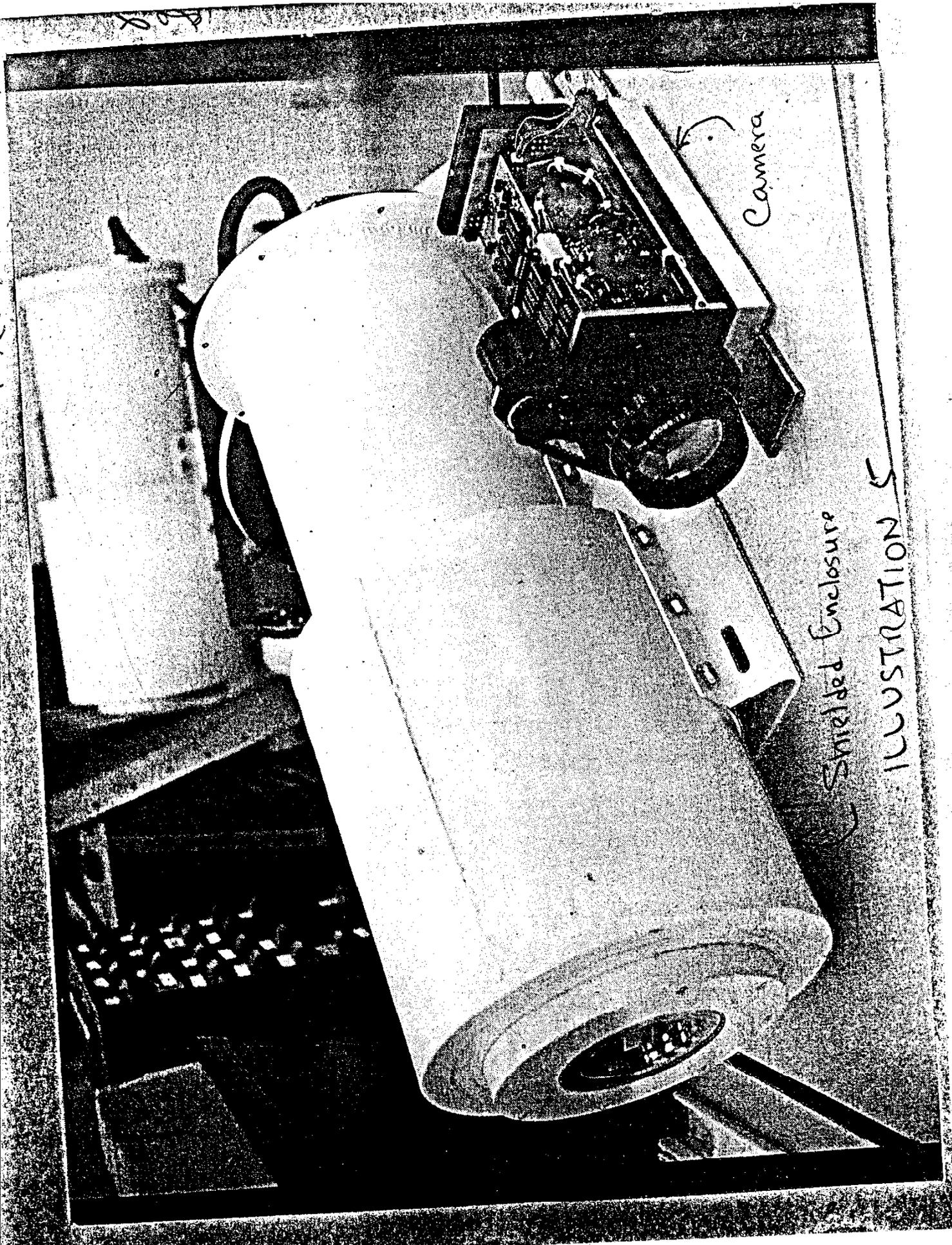
11-20



Camera before
Installation into Shielded
Enclosure

UNCLASSIFIED

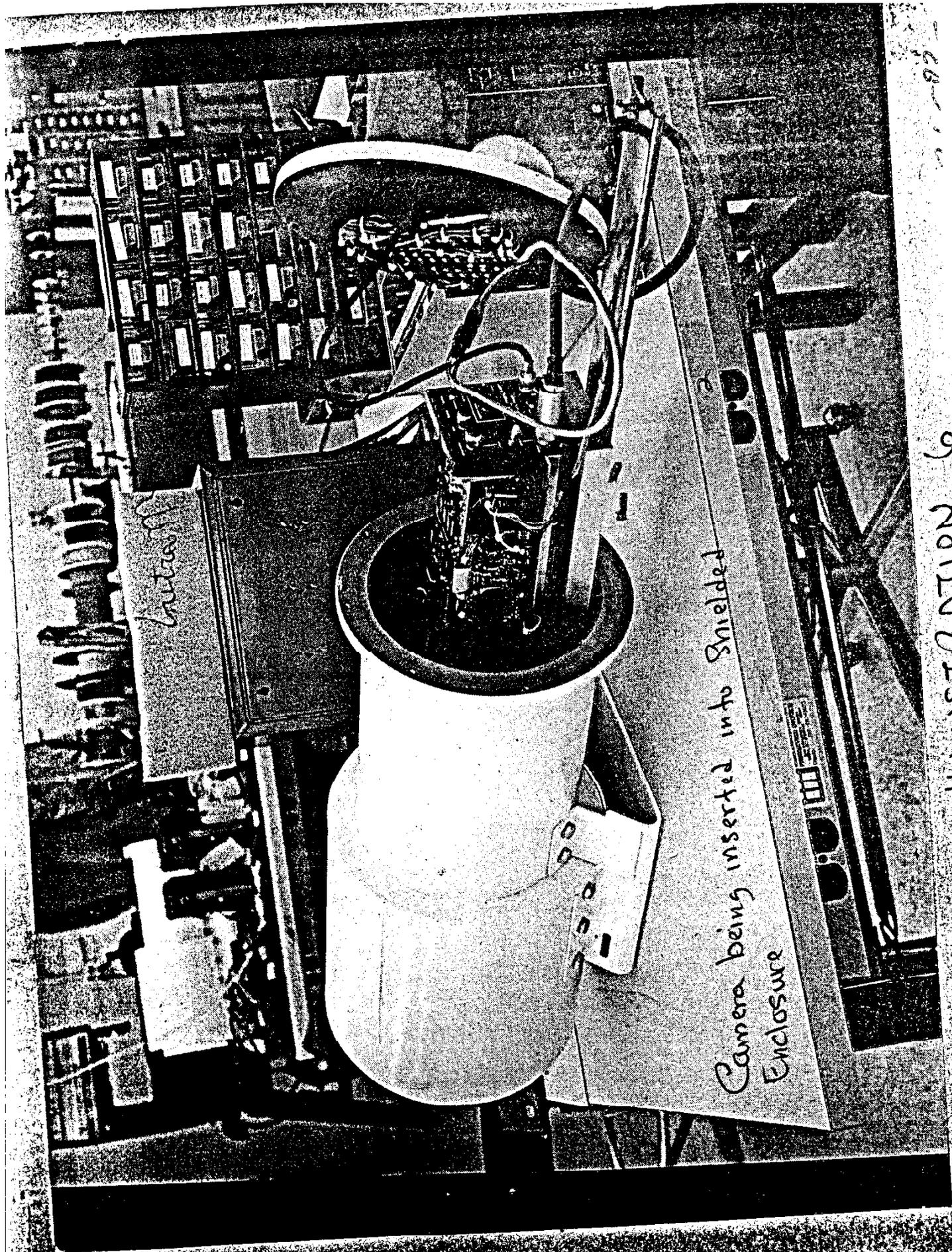
1808



Camera

Shielded Enclosure

ILLUSTRATION 5

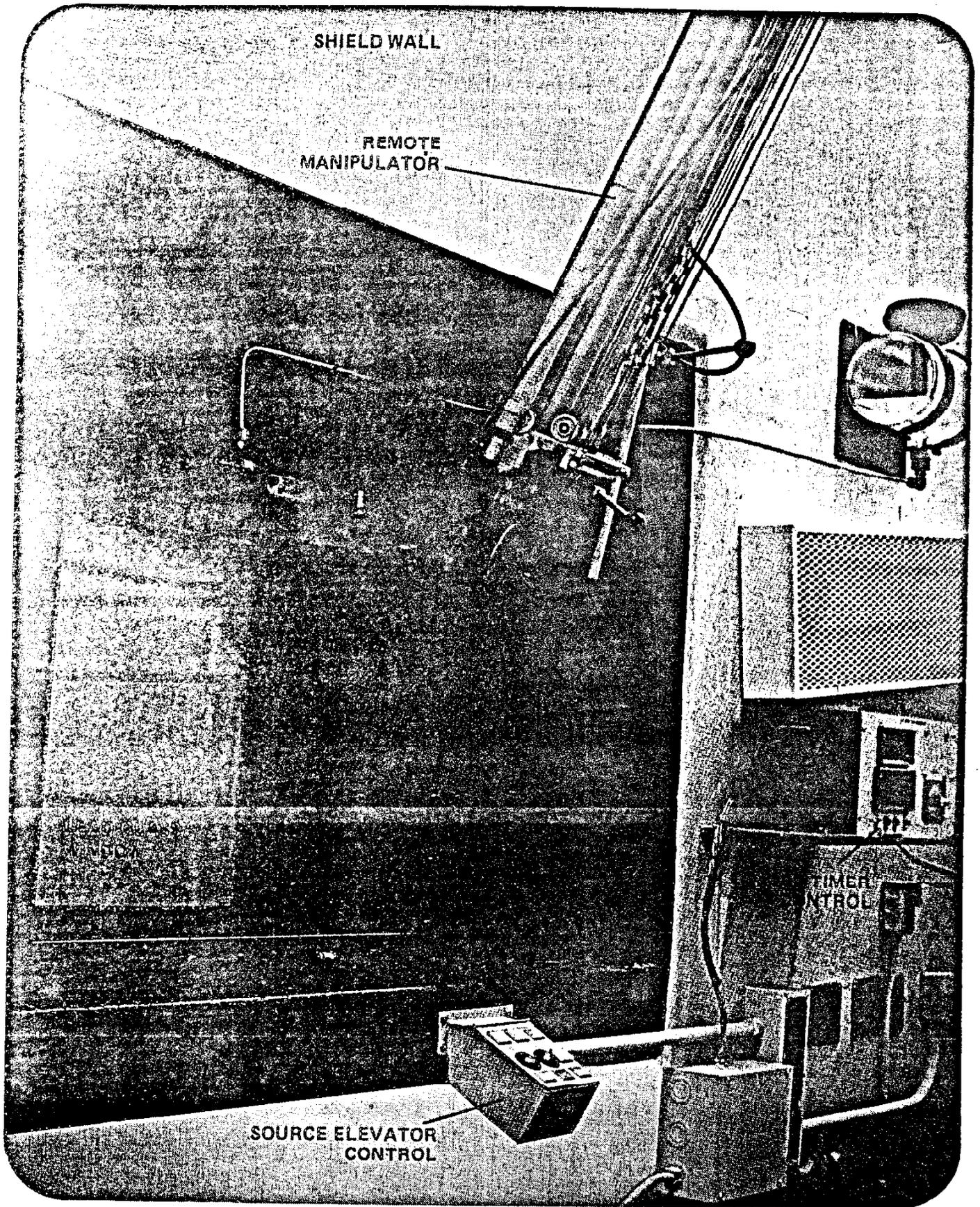


Autocam

Camera being inserted into Shielded Enclosure

ILLUSTRATION 6

Outside view of Gamma Test Cell



78-6969-4869-8

ILLUSTRATION 7

Visual Products Division/3M