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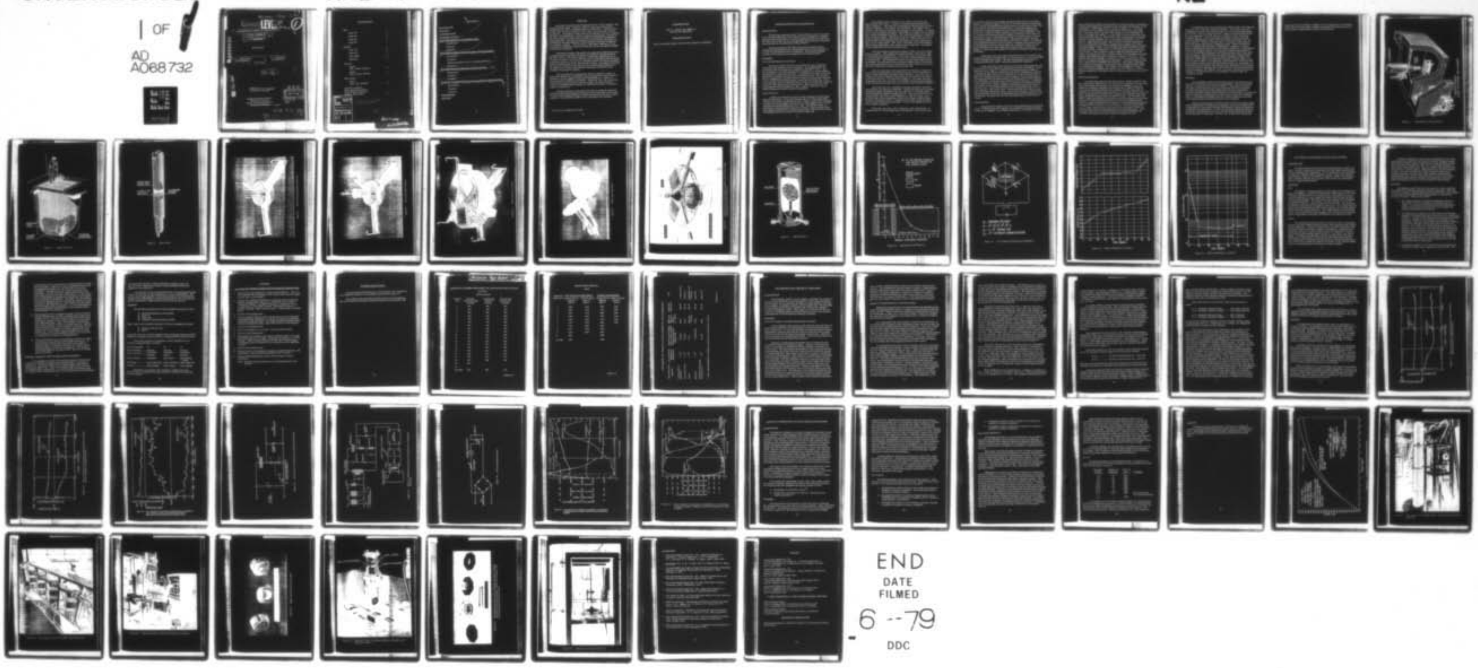

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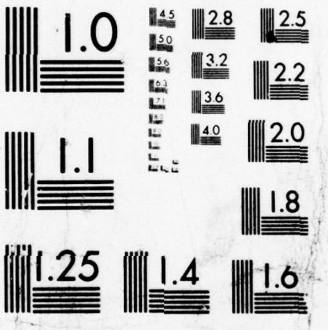

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PREFACE

The past six months have brought all phases of this program into the experimental stage. Radiation sources have been received and installed for the study of radiation effects on dielectrics. These sources include 2500 curies of Cobalt 60 and a 2 Mev Van de Graaff electron accelerator. A program of study centered around these is now in progress. The basic instrumentation is nearly complete permitting the direction of the many activities of this project towards the obtainment of applicable engineering data. With the accumulation of experimental information, it is intended to develop additional instrumentation to measure mechanical and chemical changes. Concurrently a theoretical approach will be crystallized to determine more accurately the causes of property changes resulting from radiation.

Preliminary studies with models of motors (motorettes) have been completed and the functional evaluation of insulation systems has been formally started. The initial study has provided the opportunity to learn the effects of factors such as continuous versus intermittent electrical and mechanical stresses, as well as to establish control over facets of experimental techniques that would influence the results. This phase of the work has been very fruitful and promises to have considerable importance in the significance of future data obtained with these motorettes in the evaluation of insulation systems.

The non-destructive testing and study of repetitive surges on dielectrics phases saw considerable activity during the summer months. Ionization currents appear to have good possibility as a means of determining the condition of insulation. Professor Vail, who is working with the group only during the summer months, has made excellent progress in establishing techniques for studying the effects of repetitive surges on dielectrics.

Several members of the group were able to attend the American Institute of Electrical Engineers Summer General Meeting to participate in the several meetings devoted to dielectric materials and other related subjects. Two conference papers were presented at this meeting.+

+ See section on Reports for titles.

AUTHORIZATION

N.R.L. Problem No. 33E07-01
R.D.B. No. NR 427010

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

RADIATION EFFECTS ON DIELECTRICS

INTRODUCTION

The previous progress report[1] indicated that a survey was made of the existing literature on the subjects of instrumentation, radiation techniques and of the effects of various radiative particles on dielectrics. The latter part of this survey was augmented with preliminary electrical measurements of coil specimens during radiation.

The procurement of the 2500 curie source of Cobalt 60 was initiated and specifications were being prepared for the manufacture of a 2 Mev Van de Graaff electron accelerator. Concurrently building facilities for housing the above equipment were being prepared.

PROGRESS

Van de Graaff Electron Accelerator

The Van de Graaff electron accelerator has been delivered; installation and testing are now in progress. It is expected that the accelerator will be available for research by October 1, 1953. The Van de Graaff is of vertical design and is mounted on a 10-foot platform surrounded by a concrete block wall. A minimum of two feet of concrete shielding is provided in all directions at the floor level. The electron beam is magnetically scanned at the end of the accelerator tube extension so as to sweep back and forth along a line at the rate of 400 cps. Thus, a flat speciman can be irradiated over its surface by producing mechanical motion at right angles to the scanned beam. Beam currents up to 250 microamperes can be obtained at 2 Mev. Figure 1 shows the Van de Graaff housing and control console arrangement.

Cobalt 60 Source

A 2500 curie Cobalt 60 source has been obtained from Oak Ridge National Laboratory. It has been transferred to a 12-foot deep water tank where it will be permanently housed. Figure 2 pictures the shipping container and source plate at the base of the tank together with a 15-foot manipulator used in handling the source cans. The Cobalt source is submerged in approximately eleven feet of water, which provides more than adequate shielding; the radiation background at the floor level cannot be distinguished from the natural radiation background.

The Cobalt source consists of ten source cans each with approximately 250 curies. A source can loaded with Cobalt pellets is shown in Figure 3. The cans are constructed of stainless steel and each contains 50 pellets. The pellets are cylindrical, one-eighth inch in diameter and one-half inch long, and average 5 curies apiece. As shown in the cut-away section of Figure 3, the pellets are loaded in five columns, each column containing ten pellets. The columns of pellets are separated by an aluminum spider. The top of the can is provided with a screw cap which is silver-soldered to the body of the can. The base of the can is provided with a pin arrangement for positioning the cans in appropriate holes in the source plate. The source cans have an overall length of seven and one-half inches and a diameter of one-half inch. The Cobalt columns within the cans are five inches high.

The source plate is pictured in Figure 4 with a set of ten dummy sources in place. The central disc-shaped portion of the source plate is of stainless steel construction. The source plate is provided with a series of holes in which the source cans may be positioned on circles of varying radii. The innermost circle is one and seven-eights inches in diameter, the outermost is nine and three-eights inches in diameter. The angular position of a source can about its axis is fixed in the source plate by an offset pin located on the base of the can.

Two test cells have been constructed for dielectric exposures. They have been designed for use when the source cans are located on a circle of three and three-quarters inches diameter. One test cell is designed to be placed within the ring of source cans and it is referred to as the inner test cell. It is pictured in Figure 5. The other test cell, designated as the outer test cell, is of toroidal construction (rectangular cross-section) and encircles the ring of source cans as shown in Figure 6.

The inner test cell is designed to permit continuous electrical measurements of dielectric specimens. Electrical leads may be brought through the angled extension at the top of the unit to a sample holder which supports the dielectric within the cell. The cell is constructed of stainless steel and it has a wall thickness of 1/32 of an inch. It is provided with a pin arrangement, of the same design as that located at the base of the source cans, to position the cell with respect to angle in the central hole of the source plate. A view of the opened inner test cell is shown in Figure 7.

The outer test cell, also of stainless steel construction, is provided with an 18-mil thick inner wall adjacent to the source cans.

The inside of the cell is accessible through the three parts on its upper surface. As noted in Figure 6, the cell is provided with three arm extensions to permit raising and lowering by means of a steel ring. (This ring is also used to maneuver the source plate.) A guide arrangement is employed to permit lowering this cell in position without damaging the source cans. Figure 8 shows a phantom view of this arrangement. The ten sources are in position inside the guide and directly in the center of these source cans is a centering pin (similar in construction to a source can) which is used to center the guide. The guide and guide centering pin are removable to permit the inner cell to be put in place. Irradiations made within the outer test cell are made in stainless steel specimen cans of wall thickness of three and one-half mils. Dielectric films are supported between brass rings within these sealed cans, as pictured in Figure 9. These cans are sealed to trap gaseous products resulting from irradiation.

A third test cell is now under construction of very much the same design as the above described outer test cell; however, it is to be provided with an insulated inner jacket. The use of heating plates will permit irradiating dielectrics under controlled temperature conditions.

A film calibration of the Cobalt 60 source has been performed with Eastman 548-0 film supplied by the National Bureau of Standards. Film exposures were made in a dosimeter packet developed at NBS for correcting for the energy sensitivity of the film[2]. Simultaneous with the calibration at NRL the film was calibrated in a known Cobalt 60 field at NBS to an integrated dosage of 20,000 roentgens. Errors introduced in developing the film were minimized by processing the two films together. The calibration is believed to be accurate within 15 percent. A summary of this calibration is shown in Figure 10 where the five plotted positions correspond to the positions indicated schematically within the inner and outer test cell. All of these positions are in the median plane of the active portion of the source cans. Positions within the outer test cell were calibrated with all ten source cans in place; however, due to limits imposed by film sensitivity and angulation of the incident radiation on the film packets, the inner test cell was calibrated with one source can at a time.

Instrumentation

Many dielectric films of five to ten mils thickness have resistance values of greater than 10^6 megohms and conventional measuring instruments are not capable of such high measurements. Therefore, work has been performed to develop instrumentation to measure high dc resistances. A Wheatstone Bridge was assembled using a Beckman Ultrohmeter as the null detector. The bridge circuit is shown in Figure 11. A selector switch allows for the choice of R_1 appropriate to the value of R_x under test. The instrument is provided with a guard circuit to minimize the effect of leakages and special care was taken to avoid difficulites that could arise from pick-up. The Beckman was chosen because of its good stability and rapid response time; it is capable of detecting 2×10^{-15} amperes. Measurements were made with this instrument on Victoreen and S. S. White carbon resistors having values as high as 10^{14} ohms. Very good agreement was obtained between the rated and measured values of these resistors. Also, a series of measurements on dielectric film specimens yielded resistances to 5×10^{15} ohms which were consistently reproducible. After testing the above bridge for approximately two months, its behavior became somewhat erratic and it eventually developed leakages that limited its upper resistance reading to 10^{13} ohms. It is believed that these leakages resulted from the accumulation of contaminants on components during normal operation. A second bridge has been under construction to eliminate this difficulty. The bridge components are carefully constructed to minimize possible leakages and then sealed in an appropriate container. The bridge circuit is identical to that of Figure 11 with the exception that resistor R_s is 10^{12} ohms. In view of previous experience, this should allow for measurements in excess of 10^{16} ohms.

Experimental Results

In conjunction with coil tests discussed in a former report[1] a test was conducted to determine if the decline in dc resistance during irradiation of the magnet wire wound coils was due to leakages in air, the supposition being that ionization occurring in the air spaces within the coil would be capable of giving rise to leakage currents of the order of magnitude of the currents being measured. It was found that this was true. It was concluded that the magnet wire insulation was capable of passing a charge produced in the air pockets within the coils. For the Teflon coil tested, it was found that the dc resistance would not change from its initial value of 10^{12} ohms during irradiation at a dose rate of approximately 600 R/hr. under reduced pressure; however, at atmospheric pressure the same coil showed a decline in dc resistance to a value of approximately 2×10^{11} ohms. On the basis of this result, the air pockets within the coils were eliminated by impregnating the coil with epoxy resin. It was found that there was no dc resistance decline during irradiation, the resistance remaining at 150,000 megohms throughout the test.

A preliminary test run was performed with the 2500 curie Cobalt 60 source on a five mil film sample of vinylite. The vinylite film was irradiated in the inner test cell (see Figure 5) at a rate of approximately 6×10^5 R/hr. over a period of 90 hours. Figure 12 presents the dissipation and capacitance (at 1000 cps) ~~as~~ a function of time during the irradiation period. It was noted that the readings became extremely erratic at approximately ninety hours; these data accordingly were not plotted however. Figure 13 pictures the d-c resistance measurements made both during and after the irradiation period. Within the limits of the d-c resistance data obtained, following the irradiation, it appears that the radiation induced change in the vinylite sample was of a permanent rather than transitory nature. All electrical measurements quoted are those for the parallel combination of both the specimen and the test leads to the specimen. Measurements were performed with a General Radio Megohms Bridge 744B, and a General Radio Capacitance Bridge 716C. Inspection of the dielectric sample after exposure revealed pitted areas over its entire surface. The aluminum specimen holder, which was gold-plated where it made contact with the dielectric film, was also pitted. It suggested that the dielectric was altered by the radiation in such a manner as to yield chemical products that reacted with the metal holder and hence resulted in pitting. The pitting, in turn, may have resulted in the erratic readings of dissipation factor and capacitance observed after the irradiation period.

SUMMARY

The installation of the Van de Graaff electron accelerator and the 2500 curie Cobalt 60 source has been accomplished. The Van de Graaff should be in operation by the first of October. Construction of various test cells, sample cans and accessory equipment has been completed. An initial film calibration of the Cobalt source has been performed. Work has continued to build instrumentation to measure high d-c resistances together with work supplemental to previous wire wound coil irradiation tests. A preliminary irradiation test of a vinylite sample has been performed during which electrical properties were measured.

While work of the last six month period has been associated largely with the acquisition of facilities and equipment, the next six month period is expected to be concerned primarily with dielectric specimen exposures and property measurements. A stock of some fifty commercial dielectric materials, both liquid and solid, are on hand and the acquisition of additional materials is continuing. Facilities for chemical and mechanical testing are to be provided in addition to the complete set of electrical tests, which are to be made. Further calibration of the Cobalt source is also planned to supplement the initial film calibration.

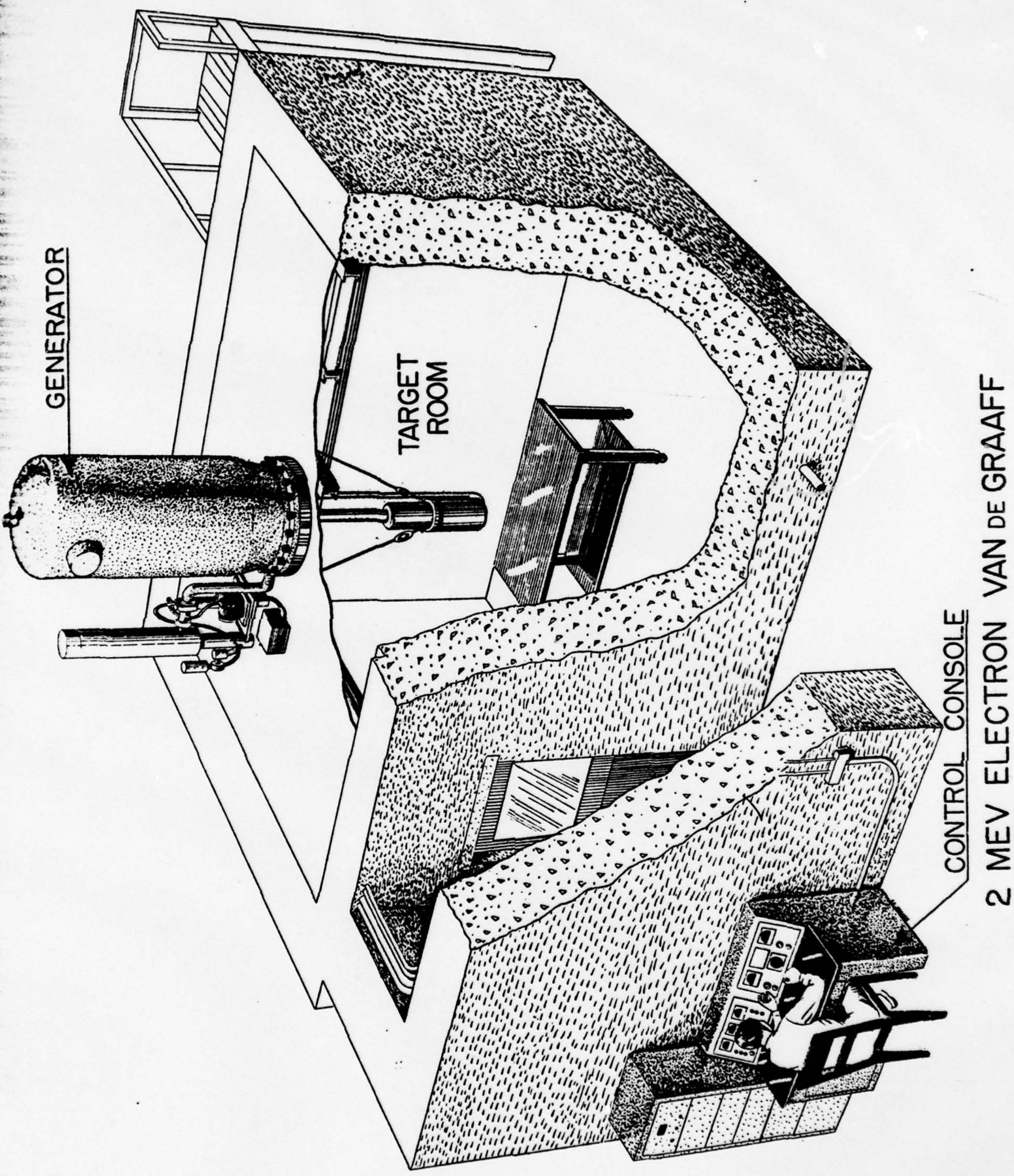


Figure 1. 2 Mev Electron Van de Graaff.

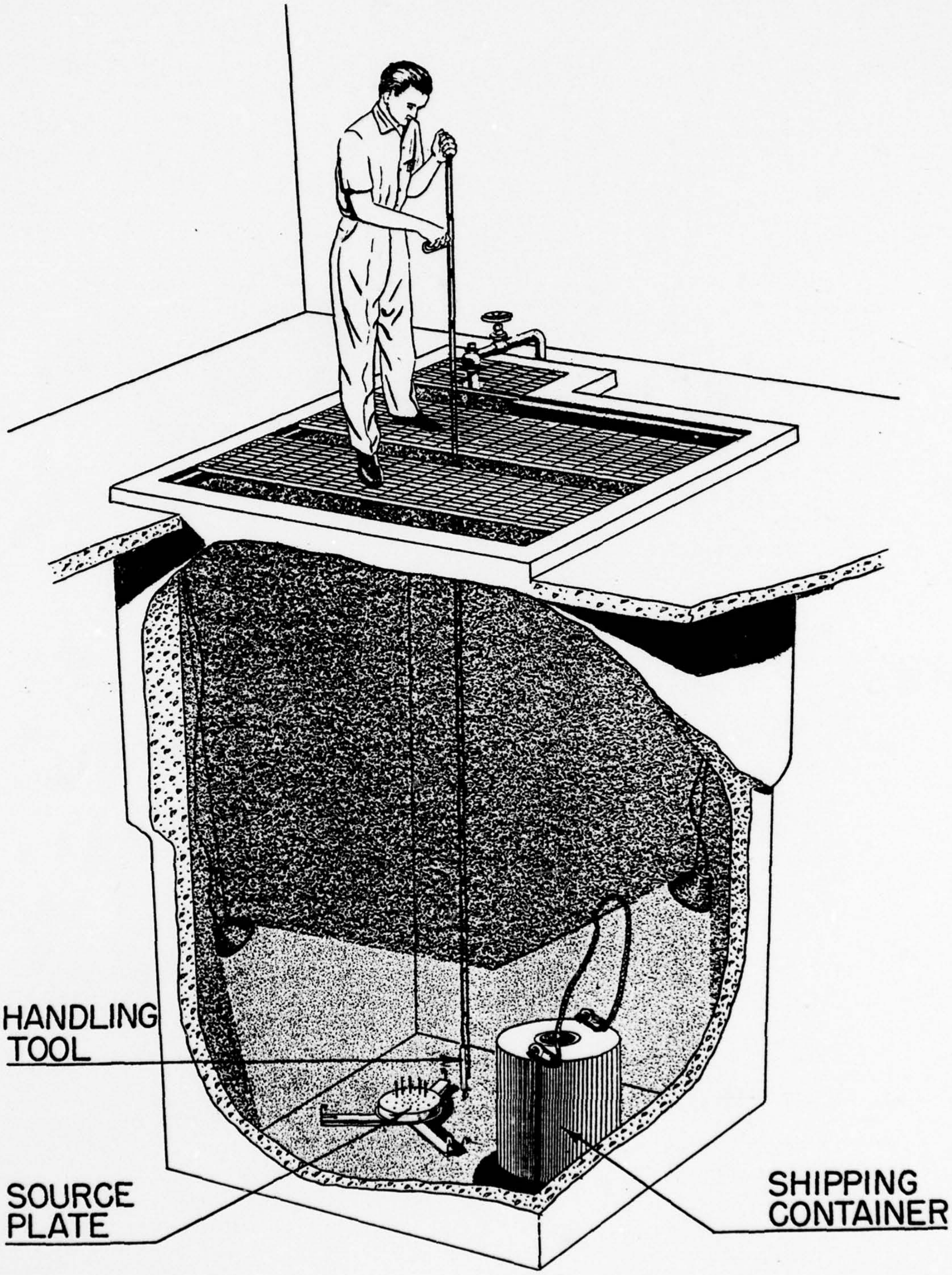


Figure 2. Cobalt 60 Source.

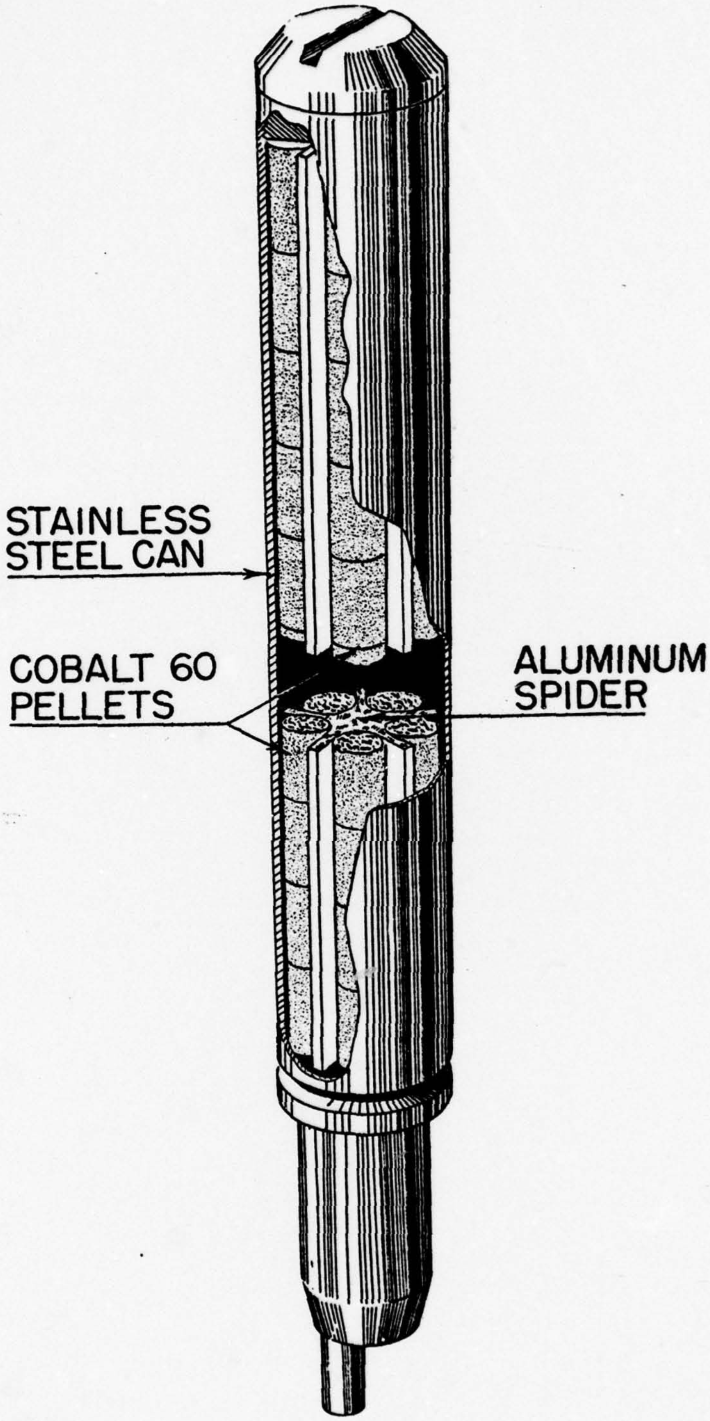


Figure 3. Source Can.

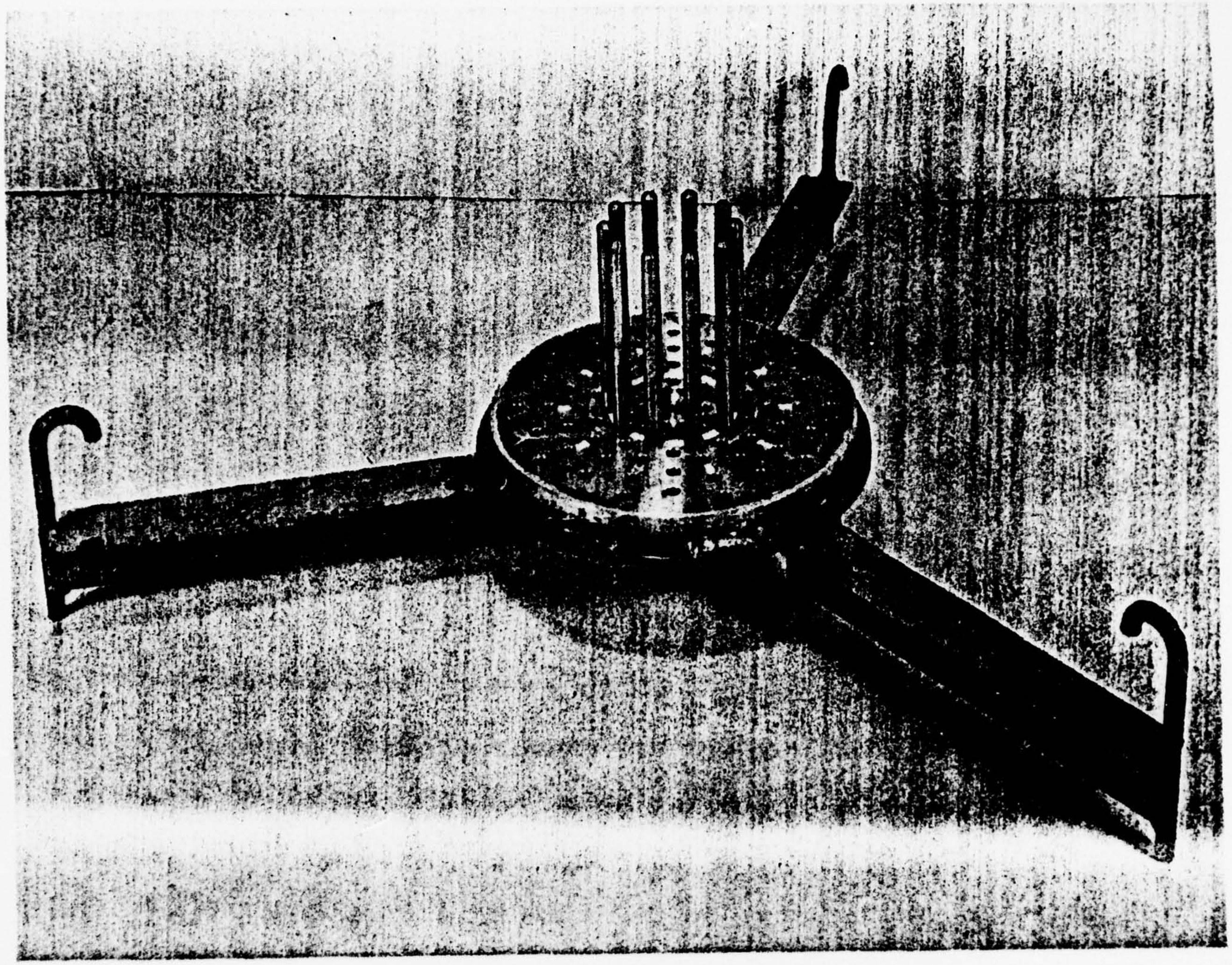


Figure 4. Source Plate and Dummy Sources.

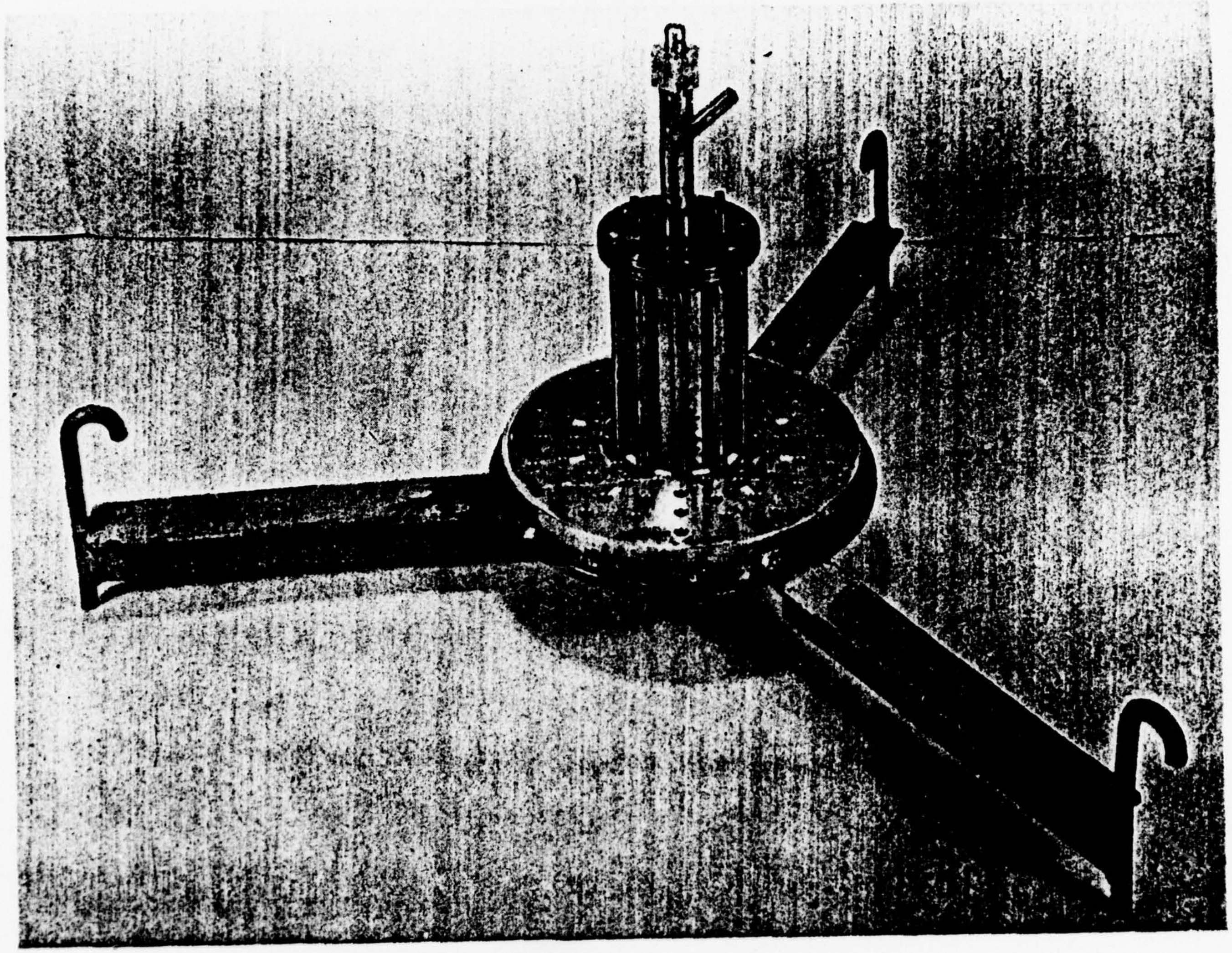


Figure 5. Inner Test Cell in Place.

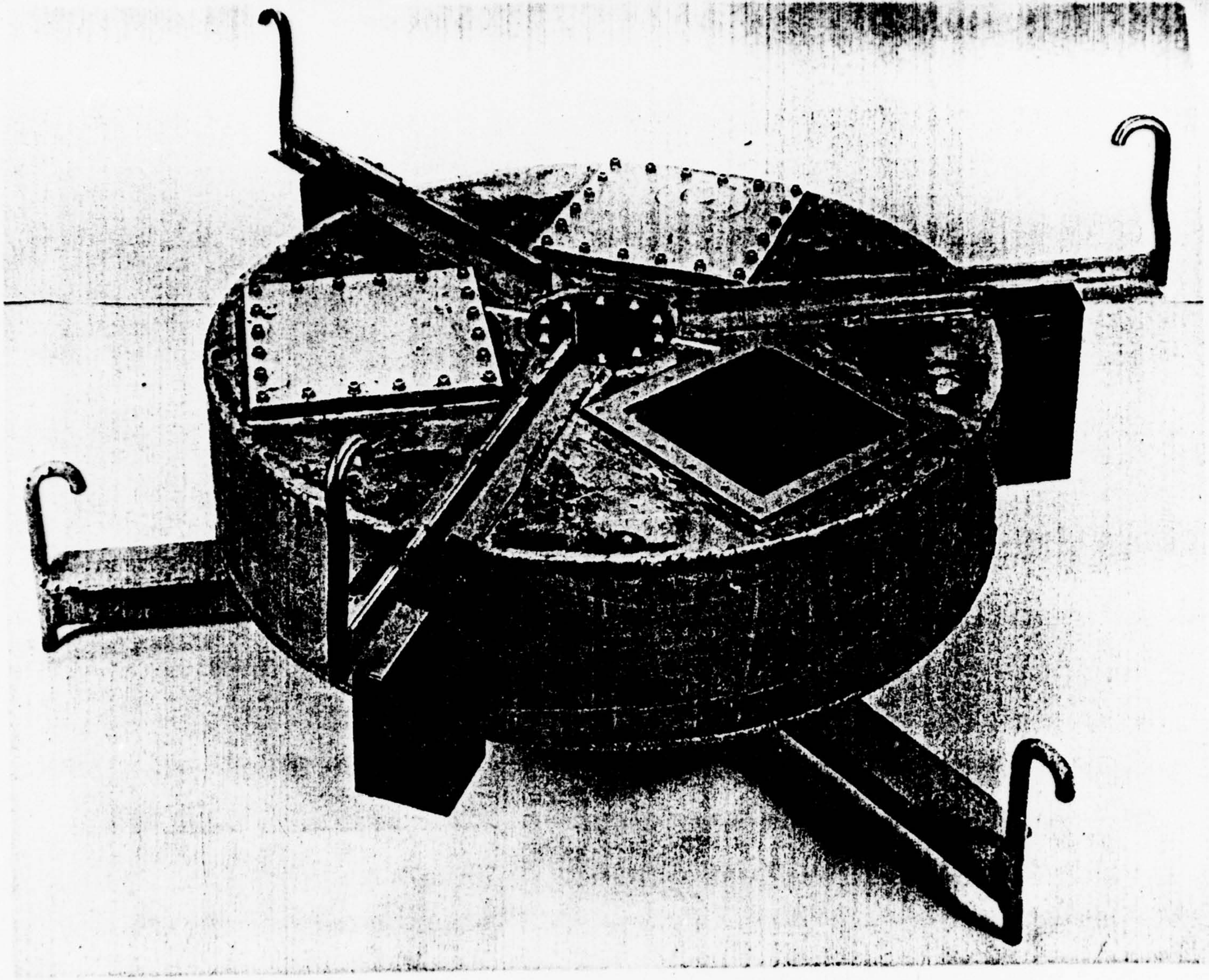


Figure 6. Outer Test Cell in Place.

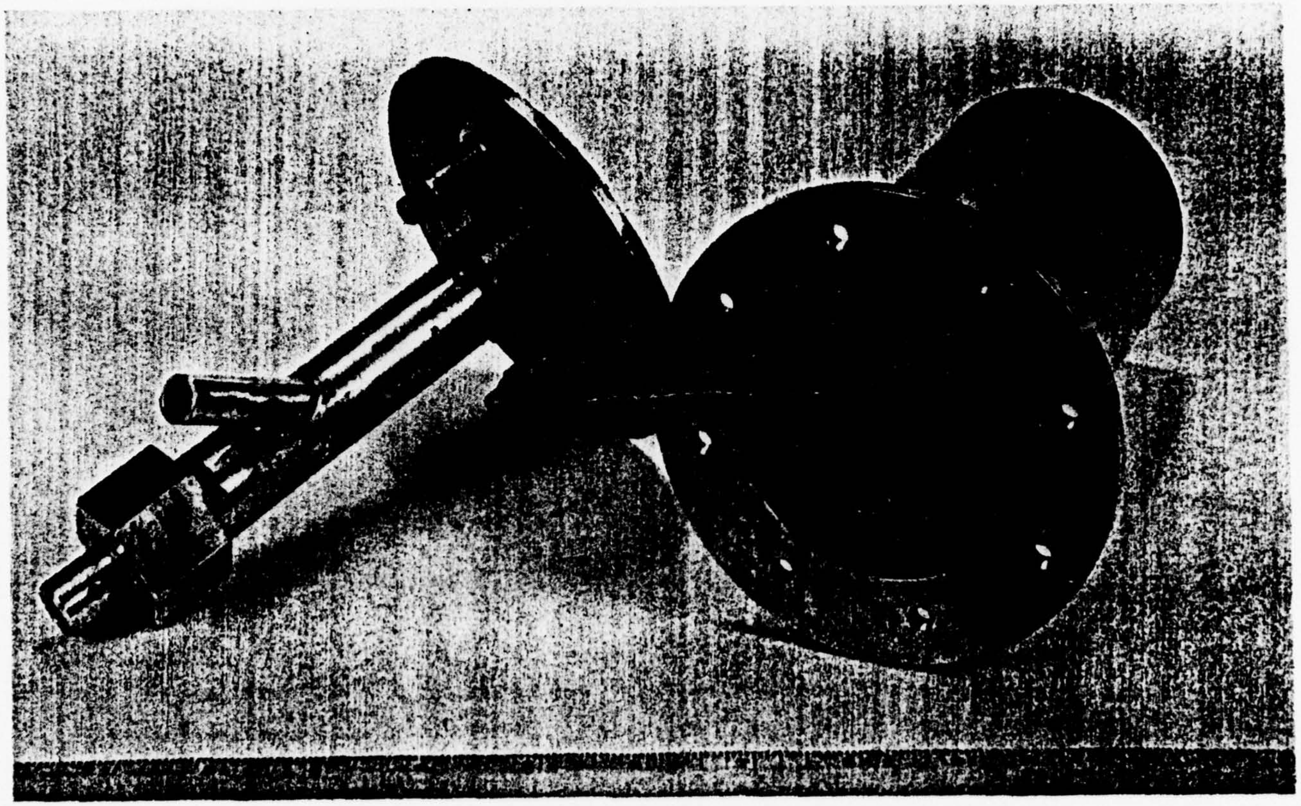


Figure 7. Open Inner Test Cell.

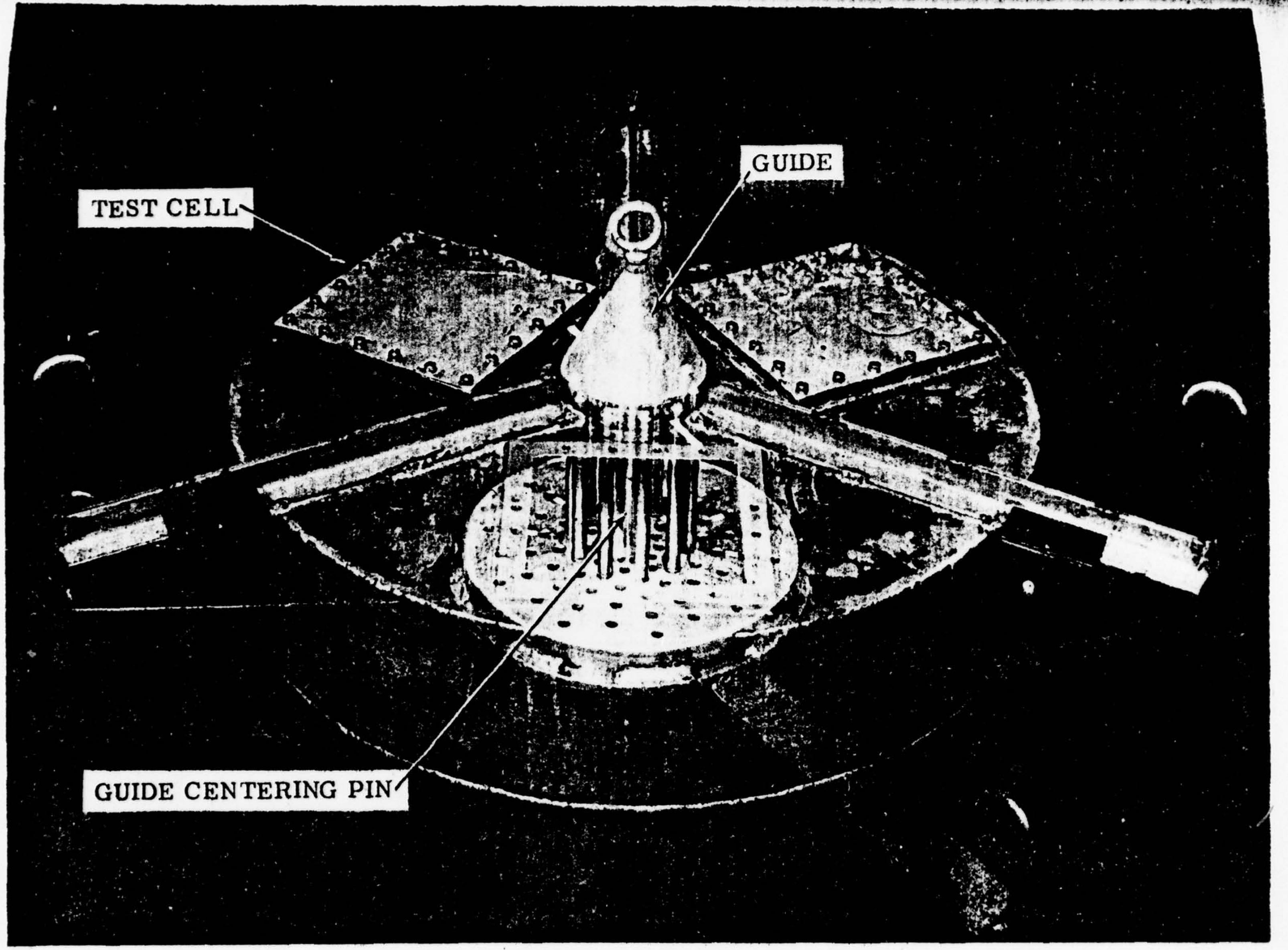


Figure 8. Phantom view of source plate, dummy source cans, guide centering pin and outer test cell.

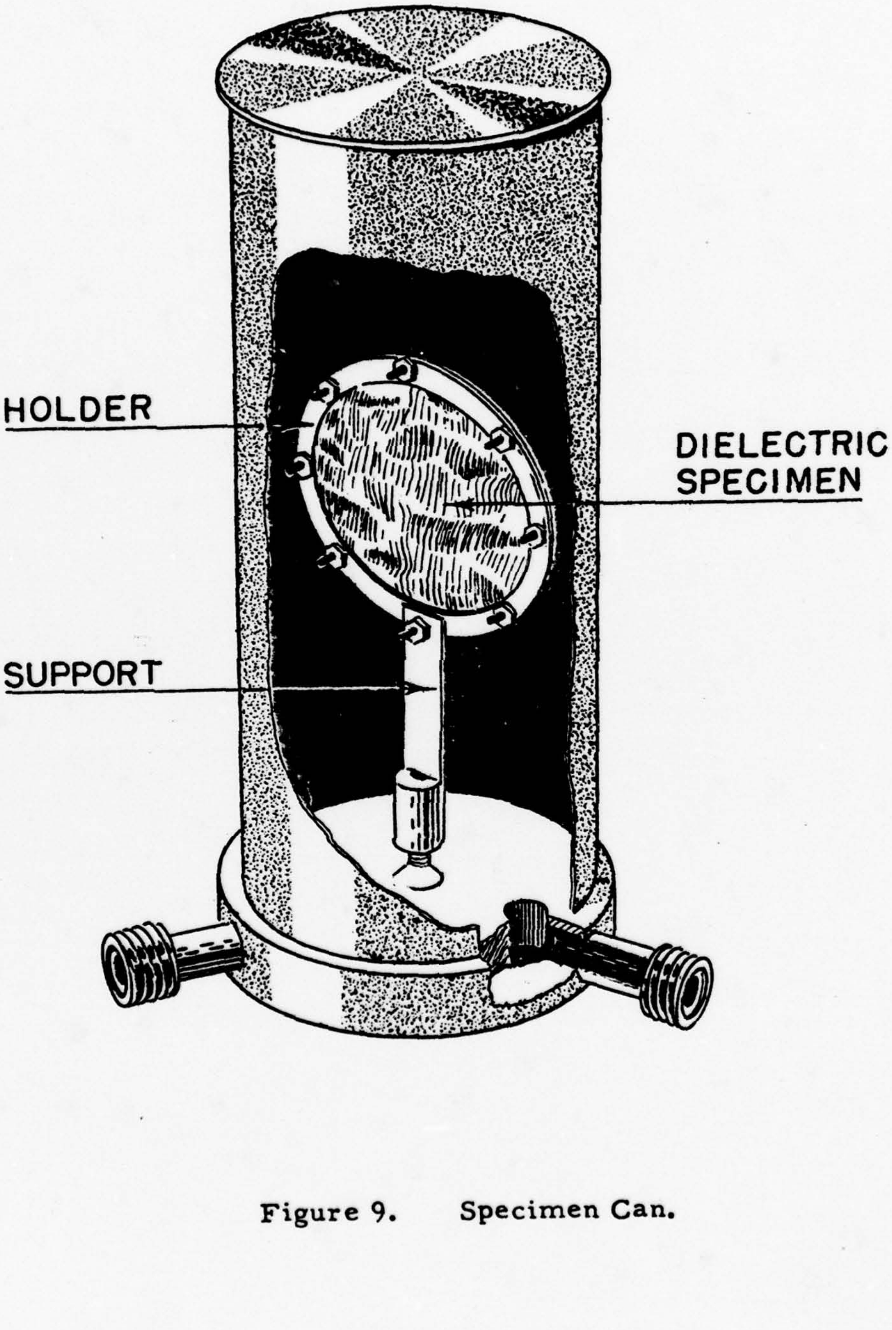


Figure 9. Specimen Can.

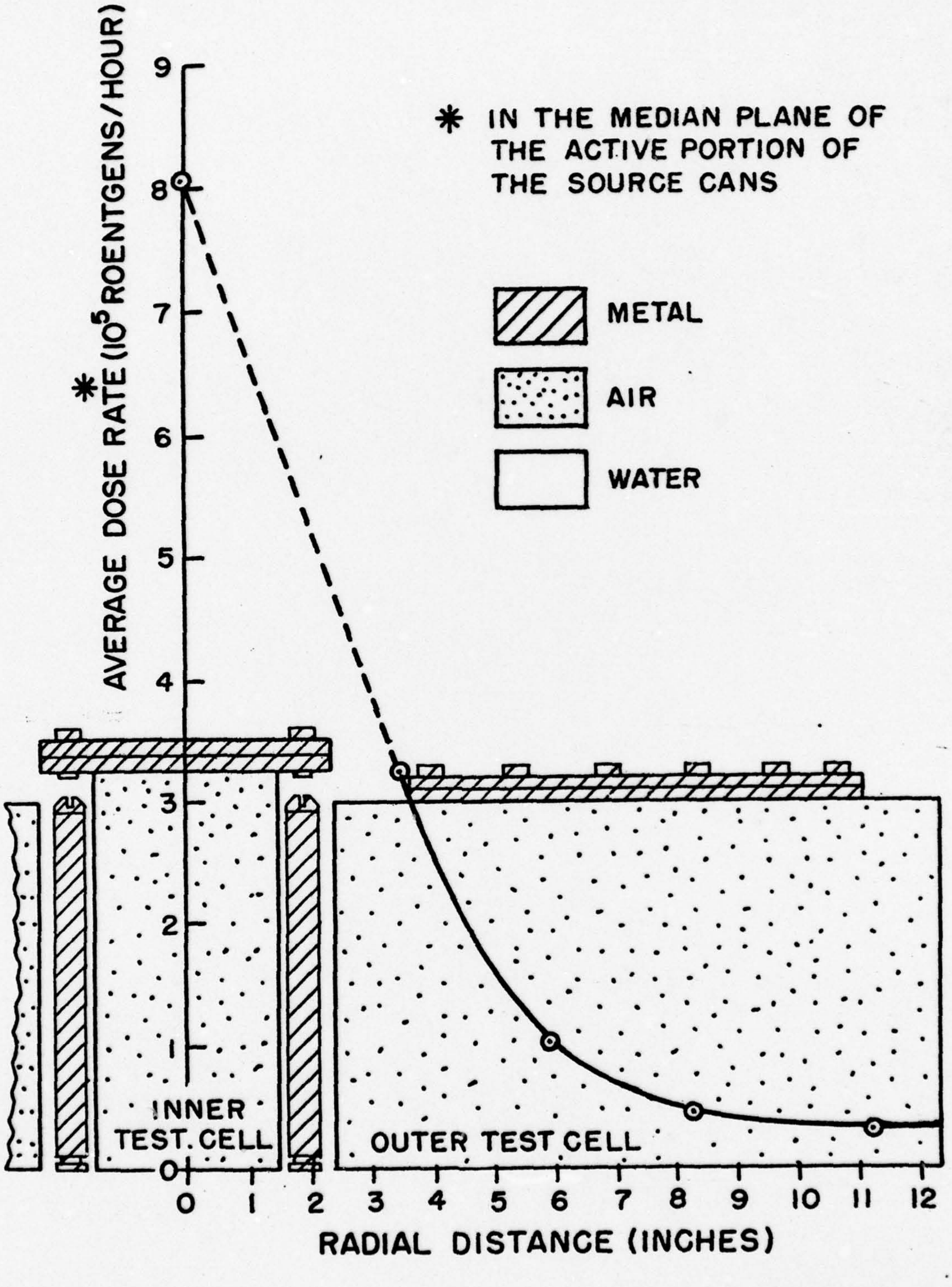
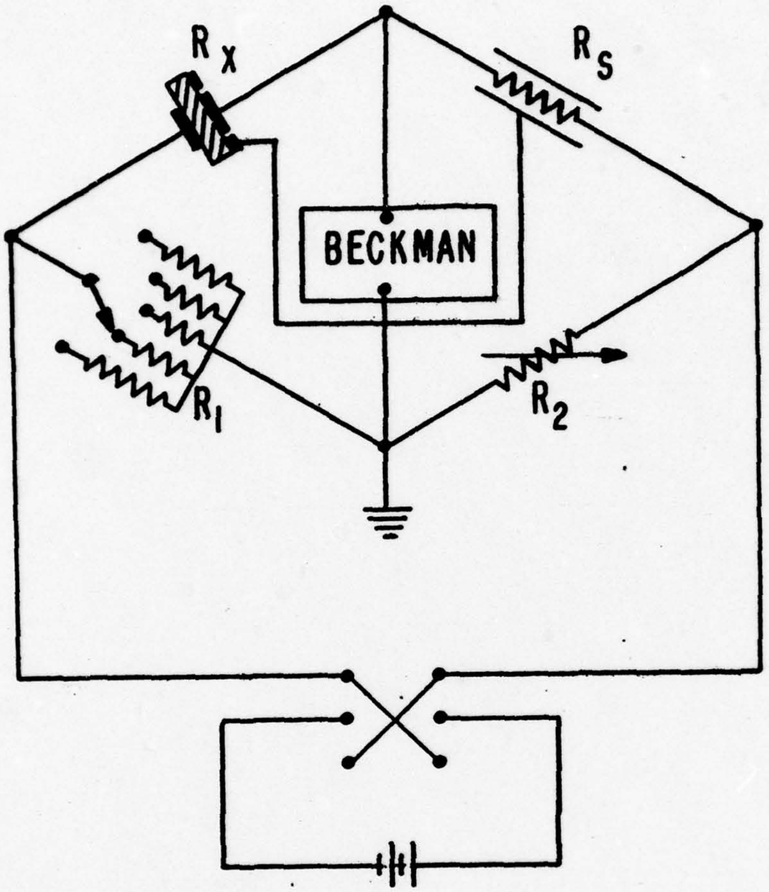


Figure 10. Calibration of Co^{60} Source.



R_X , UNKNOWN SPECIMEN

R_1 , 10^3, 10^5, 10^7, 10^8, 10^9 Ω

R_2 , 0 – 10^5 DECADE BOX

R_S , 10^{11} VICTOREEN CARBON RESISTOR

Figure 11. D-C Resistance Bridge Circuit Diagram.

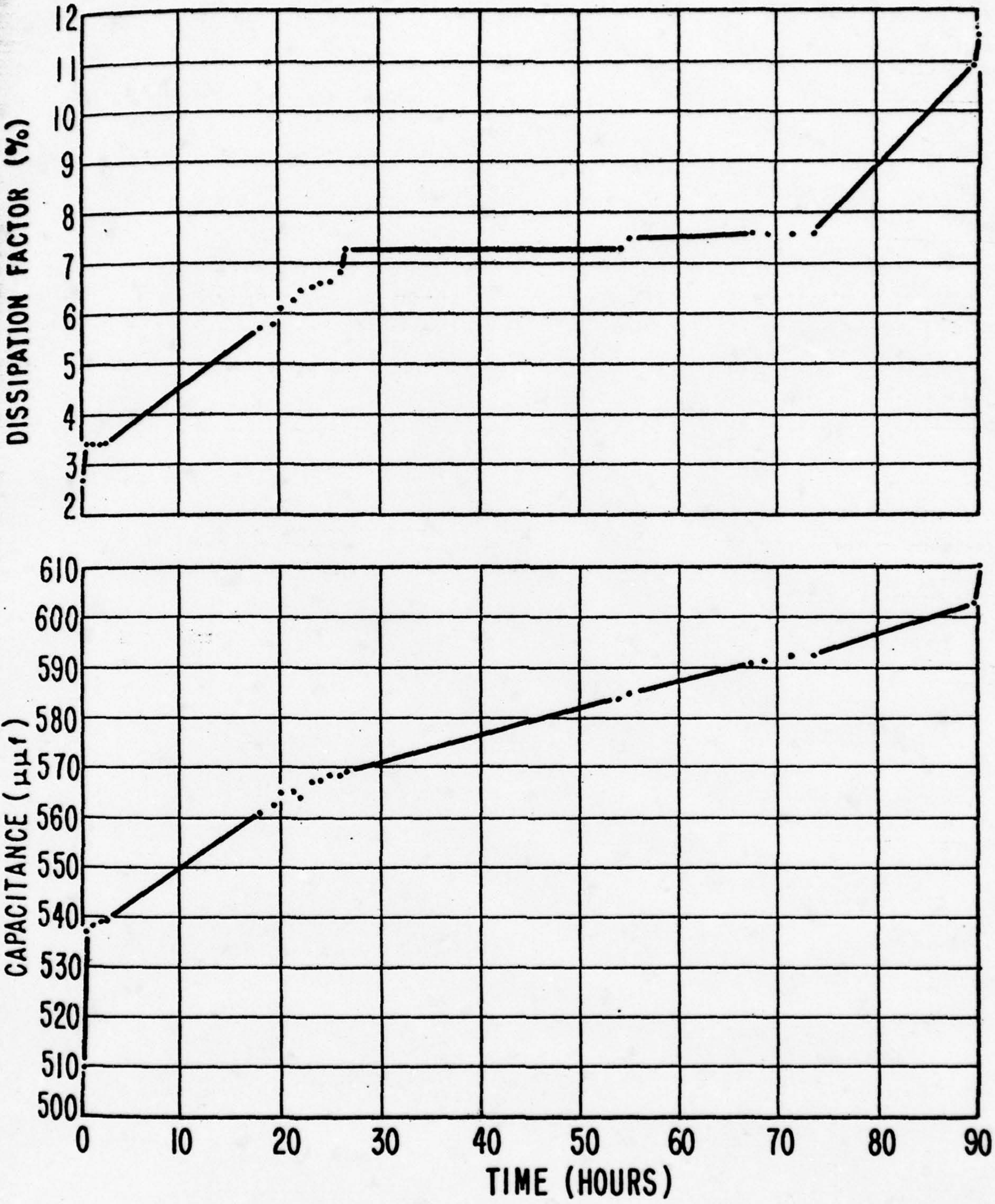


Figure 12. Effect of Radiation on Vinylite.

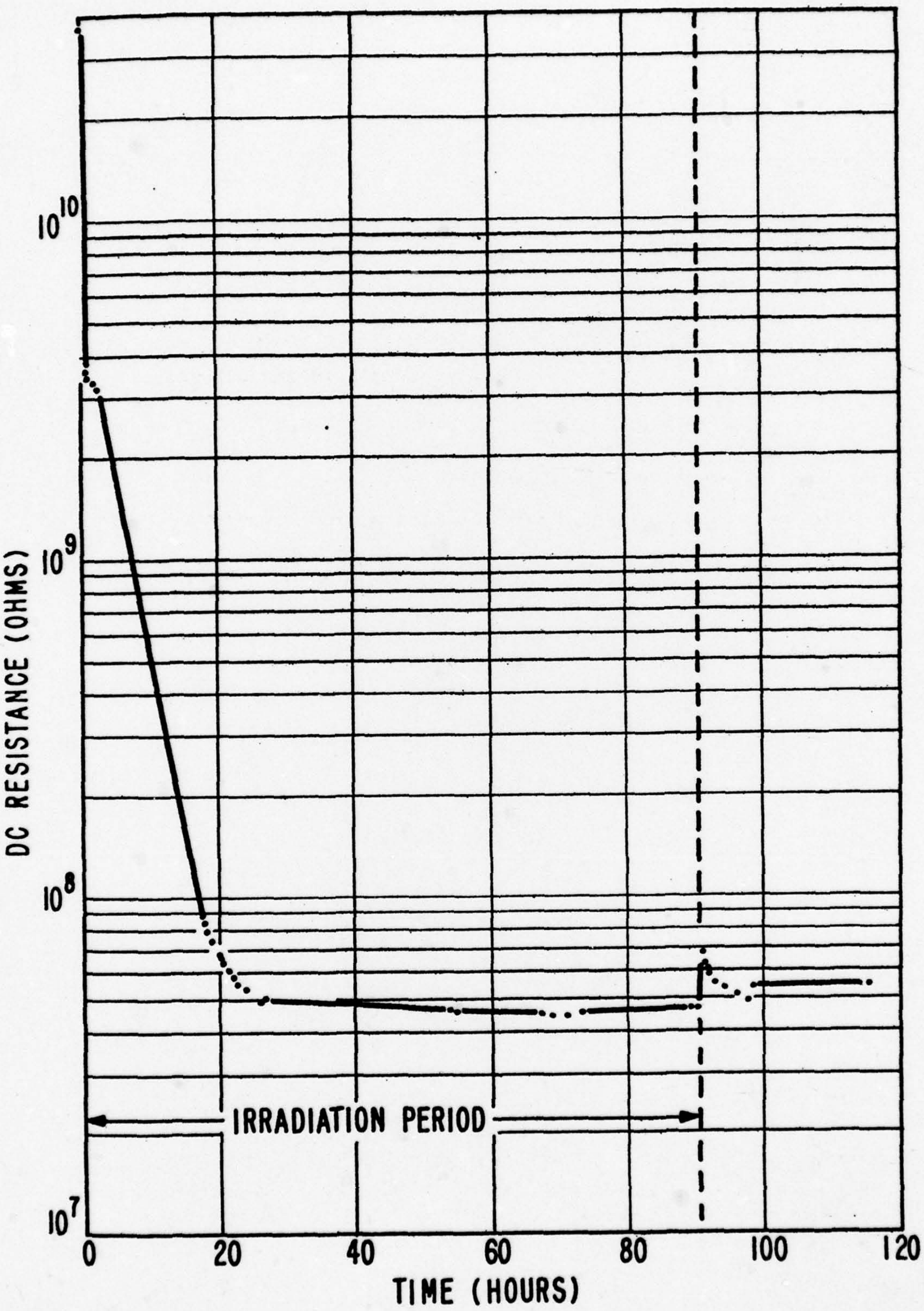


Figure 13. Effect of Radiation on Vinylite.

FUNCTIONAL EVALUATION OF INSULATING SYSTEMS

INTRODUCTION

During the period covered by the preceding progress report[1], the effects of cyclic heating and of humidity on thermal aging characteristics of wire insulation were determined. The life temperature characteristics of Teflon were obtained under condition of cyclic aging with humidity. A preliminary report on fractional horsepower motors was presented which indicated that the life of motors would exceed that determined from wire aging characteristics.

PROGRESS

Coils

The effects of varnish treatment on the magnet wire insulation are being investigated. To determine these effects, three groups of 20 coils of Formex insulated wire were prepared; two of the groups received a varnish treatment of 2 coats, dipped and baked, while the third group of coils was left untreated. All three groups were aged at 160°C according to standard procedure. The results, as shown in Figure 14, list the average life of the non-varnish treated coils as 369 hrs. The group with the GE 9574 varnish had an average life of 802 hrs. On the other hand, the group treated with the Silicone 997 varnish experienced very little change in life due to the varnish treatment. The ineffectiveness of the Silicone varnish may be attributed to poor bonding of the varnish on the insulation and/or a high degree of humidity penetrability of the Silicone varnish.

Motors

The fractional horsepower motors chosen for study in conjunction with the coil tests continue to operate longer than anticipated from results of coil aging tests. Test M-2, consisting of ten motors insulated with HF Formex wire and varnish treated, is incomplete. Sufficient data is available, however, to show certain trends and comparison with the non-varnish treated motors aged in Test M-1. The results, as given in Figure 15, indicate an 8.8% longer life of varnish treated units before flaking occurs and promise an even greater life before actual failure. It is of interest to note that all failures of the non-varnish treated motors were turn-to-turn, while the majority of failures of the varnish treated motors occurred between the starting and running windings.

Insulation breakdown in these motors is believed to occur in the following manner: After the first signs of insulation flaking are noted, the conductors rapidly loose a large portion of their insulation leaving much of the bare wire exposed. Most of this embrittled insulation is held in place in the center of the coils and between conductors thus preventing failure in these regions. High temperature and humidification, however, soon react with the bare copper surface forming such an insulating coating so as to prevent motor breakdown following the humidification cycle. When a motor does fail, it must occur between two adjacent points where the insulation has flaked off a short time before the humidity cycle prior to the formation of oxide coating.

Motorettes

The AIEE test code[3] describes the procedure recommended for the evaluation of insulation systems by utilizing motorettes. This code is tentative, however. Experimental studies indicate that certain changes are necessary to facilitate the operating procedure or improve the accuracy of results. These are as follows:

1) The sudden change to the ambient temperature will cause more stress to the insulation of a motorette than of a motor[4]. It is therefore recommended that the temperature change of motorettes be limited to the 3-to-6 degree per minute range experienced by motors.

2) The application of voltage to the units while in the humidity chamber as required by the test code also offers considerable difficulty. To achieve this goal special wires must be inserted through an opening in the chamber and attached to the specimens. The lack of space inside some humidity chambers prevents the shifting of connections from one test tray to another. As a result, it is estimated that a minimum of 300 separate wires would have to be inserted into the chamber to apply the required voltage. The removal of the unit from the humidity chamber prior to the application of the voltage is considered to be a more desirable method if the voltage is applied simultaneously to all desired parts of the motorette immediately after removal, and the specimens are covered to prevent excessive evaporation.

3) In a previous report[1] a set of test cycles for motorettes was proposed to replace those suggested in the test code. The

proposed test cycles were based on information that was available at that time. Since then, tests on motorettes have shown a considerable deviation the life expectancy previously anticipated. Operation at the test cycles proposed by the Laboratory, or by the test code, would result in many more cycles than necessary to obtain reliable data. It is now evident that no combination of temperatures and heating cycle lengths will be ideal for all insulations. Therefore, it is proposed the test code be changed to require only that the number of cycles to failure be approximately 15. This would permit the attainment of the goal of the investigation, i. e. the establishment of the life-temperature characteristic of the insulation without handicapping the test procedure.

4) While planning tests on insulation systems it became obvious that the silicone glass laminate terminal blocks would not be suitable for use. During the tests on Class H materials they would age as rapidly as the insulation and may be the source of an indicated failure. Also, the electrical measurements taken of the materials would be erroneous due to the influence of the terminal block. In the search for a substitute several materials were investigated as to their qualities and costs (Figure 16). The procelain standoff insulations were found to be superior to all other materials tested, and, at present, are being used on motorettes undergoing tests.

5) During preliminary tests on motorettes, excessive corrosion of the frames occurred due to the humidity exposures. To prevent further deterioration the frames were cadmium plated and given a chromate treatment. The details of this plating procedure is found in the Appendix. This coating is not recommended for use above 321°C, which is the melting point of cadmium.

THERMAL STABILITY TEST OF INSULATING MATERIALS

An investigation to obtain the breakdown strength of twisted wire samples as a function of aging time has been planned. Two pieces of magnet wire, one foot in length, will be twisted together according to specification JAN-W-583. These wire samples will be aged in an oven at a predetermined temperature. At certain periods of insulation aging ten samples will be removed from the oven and broken down at high voltage.

The results will provide a voltage breakdown strength versus life characteristic, which may be useful in predicting life temperature properties of the dielectric.

A test similar to the one described above, but substituting straight sections of wire for the twist specimens, is also contemplated. The sections will be aged together with the twist samples, but the breakdown strength will be determined by immersing the wire in a two-inch mercury bath and applying the voltage between the wire and the mercury.

SUMMARY

The following insulations are being evaluated at present on coils:

1) HF GVT (Fiberglass and Formex)
2) Ceroc T
3) Ceroc 200
4) Silicone varnished fiberglass (G2H)

Other magnet wire insulations planned for future investigations include:

1) Silicone enameled wire
2) Nylon

At present, Class A, varnish-treated motors are being evaluated at 140°C. Operation of similar motors at 160°C is contemplated for the near future.

Two series of tests on motorettes at 180°C and 200°C are in progress using materials as follows:

No. of Motorettes	10	10	10
Wire Insulation......	Formex	Formex	Formex
Phase Insulation.....	Varnished Cambric	Varnished Glass	Varnished Cambric
Slot Insulation......	Fishpaper	Mica Glass	Rope Acetate Paper
Slot Wedge..........	Glass Melamine	Glass Melamine	Glass Melamine
Varnish............	Clear Baking	Clear Baking	Clear Baking

Evaluation of insulations with continuous voltage stress and vibration will be conducted when the insulation is believed to be effected by such stresses.

APPENDIX

Instructions For Cadmium Plating and Chromating Of Motorette Units

1. Degrease in a vapor degreaser using trichloroethylene. Time required depends on the thickness of oil and/or grease (usually ranges from 30 secs. to 2 minutes).
2. Remove non-metallic contamination by placing unit in electrolytic alkaline cleaning bath using 8 ozs. of Matawan 30-W solution (supplied by Hanson, Van Winkle Mining Co. of Matawan, N. J.) or equivalent, in one gallon of water. Electrolytic clean for 5 minutes, cathodic, then 2 minutes anodic. Temperature of solution 200°F.
3. Rinse in cold running water.
4. Remove metallic oxides (rust) by placing unit in a non-electrolytic acid pickling bath consisting of a one-to-one ratio of concentrated hydrochloric acid and water. The length of pickling depends on the amount of oxidation (usually ranges from 30 secs. to 15 minutes).
5. Rinse in cold running water.
6. Dip for 30 seconds in a 4 oz./gal. sodium cyanide solution.
7. Rinse in cold running water.
8. Electroplate in a solution consisting of cadmium oxide 3.5 oz./gal. and sodium cyanide 17 oz./gal. Operate at 30 amps/sq. ft. for 40 minutes. With a cathode efficiency of 96%, the resultant plating will deposit 2 mils of cadmium on the motorettes on all significant surfaces.
9. Rinse in cold running water.
10. Dip for 15 secs. in a solution consisting of sodium bichromate, 150 grams/liter, and concentrated sulphuric acid, 9 cc/liter.
11. Rinse in cold running water and air dry by means of forced convection.

Note: Technical grade chemicals are used throughout the above process.

Porcelain Terminal Posts

The procelain terminal posts are 1/2" diameter, 5/8" length and are designated as grade L-5 according to Specification JAN I-10.

The location of the porcelain terminal posts can be the same as the terminal posts of the glass laminate terminal blocks presently used.

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EFFECTS OF VARNISH TREATMENT ON INSULATION LIFE OF COILS

At 160°C

(Life in Hours)

Failure No.	Formex Non-Varnished Treated	Formex and GE 9574 Varnish	Formex and Silicone 997 Varnish
1	201	689	201
2	222	689	201
3	298	689	302
4	298	689	302
5	309	790	302
6	309	790	302
7	309	790	302
8	397	790	302
9	397	790	302
10	397	790	400
11	397	791	400
12	397	801	400
13	397	891	400
14	397	891	400
15	397	891	400
16	398	891	420
17	497	891	497
18	497	894	497
19	497		
20			
Average	369	802	352

Figure 14.

MOTOR TEST RESULTS

140°C

Sequence of Occurrence	Non-Varnish Treated Motors		Varnish Treated Motors	
	Time to Cause Flaking (Hrs.)	Time to Cause Failure (Hrs.)	Time to Cause Flaking (Hrs.)	Time to Cause Failure (Hrs.)
1	1200	1345	1475	1600
2	1300	1614	1475	2202
3	1540	1733	1600	2628
4	1540	2137	1733	3102
5	1540	2285	1733	3302
6	1733	2335	1833	3467
7	1733	2346	1833	
8	1733	2436	1833	
9	1839	2473	1833	
10	1839		2048	
Average	1600		1740	

Figure 15.

COMPARISON OF TERMINAL BLOCK MATERIALS FOR MOTORETTES

Terminal Block Material	Dry Insulation Resistance (Megohms)	Insulation Resistance After 3 days in 100% Relative Humidity (Megohms)	Effect of Thermal Shock 0 - 290°C	Cost Per Motorette	Life
Silicone Glass Laminate	$> 10^6$	40,000	None	$2.00	1 silicone test
Porcelain Posts	$> 10^6$	26,000	None	$1.00	Indefinite
Pyrex	$> 10^6$	0.02	None on 1 sample	$2.00	Indefinite until breakage
Mycalex	$> 10^6$	1 (Unstable)	None	$1.00	Indefinite
Mycalex with coating of silicone oil	$> 10^6$	10,000	None	$1.00	Indefinite+

+ May require additional coatings of silicone oil from time to time.

Figure 16.

NON-DESTRUCTIVE TESTING OF INSULATION

INTRODUCTION

The preceding report[1], on this subject, presented the results of dielectric measurements on Formex insulated coils during intermittent thermal aging, and on composite insulation structure during continuous thermal aging. In addition, similar, but incomplete data, was presented for Glass-Formex and Teflon insulated coils and Formex insulated fractional horsepower motors. This report is concerned with the presentation of completed data on the above phases as well as an outline of a new approach to non-destructive testing of insulation.

PROGRESS

Dielectric Changes in Insulation During Thermal Aging

It was indicated in the previous report that two coil specimens of glass Formex insulation were being aged at 250 and 270 degrees Centigrade respectively. It was noted also that the dissipation had decreased, approaching a constant value beyond 30 and 20 hours for the two aging conditions of 250 and 270 degrees Centigrade respectively. Figures 17 and 18 represent the completed data to date. It is to be observed that no significant change exists beyond these periods.

Dielectric measurements were taken also on several varnish impregnated motors during thermal aging. Figure 19 illustrates the changes in capacitance, dissipation and dry insulation resistance of a typical motor. The capacitance and dissipation were measured between running winding and frame, while the resistance was measured between all windings to ground. Examination of this figure reveals a decreasing capacitance with aging time. This reduction in capacitance is attributed to the shrinking of winding insulation from the loss of volatile fractions in the insulation. The dry insulation resistance, measured with a GR Type 544-B megohm bridge, reaches a peak value at about 1000 hours. The dissipation appears to reach a minimum at about 1000 hours and remains generally constant thereafter. Flaking of insulation was first observed at the end of 1470 hours, while actual motor failure occurred at the end of 1600 hours. The behavior of the insulation resistance and dissipation factor is in agreement with previous observations[5], namely, that the embrittlement of the insulation (a condition preceding failure) reflects loss of plasticizer. This is noted by the reduction in dielectric losses owing to reduced mobility of the ionic and dipolar groups of the material. It is revealed also that the distinct variations in the dielectric properties observed in the study of Formex insulated coils[5] were not obtained. The motor represents a system of a number of insulation components in which the dielectric measurement obtains a composite characteristic of a number of dielectrics. The characteristics of the group may not change as sharply as those of the individual component.

Changes in Incipient Ionization of Insulation Aging

Experience with dielectrics has demonstrated that degradation due to thermal aging generally results in changes in the mechanical properties of the material. These changes may appear as embrittlement with formation of fissures or voids, or, in the case of Teflon, plastic flow changes the uniformity of the insulation cross-section with a consequent change in the uniformity of stress.[6]

It is conjectured that any formation of voids with occluded gas, or any change in the symmetry of the insulating barrier will tend to lower the voltage at which incipient ionization will be observed. This view is based upon well known facts that the ionization potential is generally lower for gases than for solids. The lower dielectric constant of the gas, with respect to the surrounding solid material, establishes high voltage gradient in the gas and hence a greater susceptibility to ionization. When insulation symmetry around a conductor is disturbed, it becomes apparent that the gradient increases on the portion of insulation that has reduced its cross-section thus encouraging ionization in that section.

In consequence of the above views, existing means for measuring incipient ionization were reviewed. Several methods for detecting ionization have been used during the last 20 years. These methods include the Schering Bridge, radio noise meter, and oscilloscopic technique to detect small voltage changes. The shortcomings of the Scherring Bridge lies in the necessity of frequent bridge balances and instability near balance.[7] The radio noise method of detection also has several drawbacks. Stray interference will be picked up and detected along with voltages due to ionization currents. Values assigned to ionization levels, in this method, are dimensionless due to absence of electrical connection between specimen and detecting circuit.[8] In 1940, G. E. Quinn improved upon previous methods of detecting corona by use of the oscilloscope.[9] The circuit is represented in Figure 20. Two inductances, L_1 and L_2, in series with the test specimen experience a voltage drop due to high frequency ionization currents in the specimen. The inductance L_1 is a honeycomb wound coil of about 4 henrys. The inductance L_2 consists of a radio frequency coil of about 4 millihenrys and a distributed capacitance of about one micro-microfarad which acts as a parallel resonant circuit at some frequency of the ionization currents. The capacitance C provides a low impedance path for the ionization currents. Since this capacitance is directly across the high voltage source, it acts as a low-pass filter to ground for noise picked up in the circuit and, for this reason, a test can be made by disconnecting the capacitance to determine if ionization or random electric noise is being detected.

The Quinn circuit has been chosen as a basis for the N. R. L. instrumentation, as shown in Figure 21. Due to the large amounts of high frequency noise coming through the power lines, two isolation transformers have been connected in cascade. A variac serves to vary the input of the high voltage transformer. The capacitance across the output of the variac is used to eliminate the "hash" due to the varying brush contact of the variac. The high voltage transformer is shielded, as well as all wires and components following it. The voltage rating of the transformer is determined by the type and thickness of insulation to be studied. The large capacitance C across the output of the high-voltage transformer is composed of two 0.076 microfarad capacitors in series to obtain a voltage rating of 20 KV. The inductance L_1 is a 7.6 henry swinging choke. This component was used since no honeycomb coil of a large value was available. The inductor L_2 is a 5.5 millihenry radio frequency coil with about one micro-microfarad distributed capacitance. The paper gap across these two inductors provide protection in the event of specimen breakdown and full voltage appears across the two inductors.

The small voltages due to the ionization pulses are amplified by 40 DB to obtain a working sensitivity. Since there was considerable "pick-up" noise in the circuit, and since the amplifier also increased the amplitude of all the low frequency signals not taken out by the two inductors, a high pass filter was designed to pass frequencies above 10 KC. Later a second filter was designed for 100 KC and was placed in series with the first. This permitted the use of full gain of the oscilloscope amplifiers. This arrangement was satisfactory for samples being tested inside a shielded box, but for tests performed in unshielded ovens, an inductance of 11 millihenrys acting as a third high pass filter had to be added.

When samples are to be tested with d. c. voltages, a variable d. c. power supply is used for stressing the specimens. The filtering networks, however, are applied to d. c. as well. The essential distinction that can e made between a. c. and d. c. voltages is in the type of pulse viewed on he oscilloscope. The ionization caused by a. c. voltage tends to appear t the positive and negative peaks of the waveform and therefore appear n regularly spaced intervals. On the other hand, ionization caused by . c. voltage is random and is much harder to distinguish from the normal pick up" noise.

It is rather difficult to determine the starting point of ionization y visual inspection of oscilloscope. The measurement depends upon the bserver and the sensitivity of the detecting equipment. A quantitative measure is more desirable and has been obtained with the use of a microammeter circuit, Figure 22. The microammeter measures the rectified current of the amplifier output. An external d. c. voltage and adjustable potentiometer is used to balance out the background noise, thus permitting the microammeter needle to be set on zero prior to stressing the specimen. With this technique, incipient ionization voltage may be defined at an arbitrary level of ionization current. When this circuit was used, a level of 10 micro-amperes was considered as representing incipient ionization.

Film samples were held between a flat electrode representing an equipotential plane and a circular piece of brass with an area of 25 square centimeters. The edges of the latter electrode are rounded (1/8 inch radius) in conformance with standard practice. The sample, 3 x 3 inches square, is held tightly between electrodes by screw adjustment. These electrodes sit in a pan which can be filled with oil so that the specimens can be tested in air or under oil.

The results of tests on a 10 mil sample of Teflon show the comparison of the ionization starting voltage in air and in oil as follows:

In air .... 135 peak volts/mil (min 113 - max 156)
In oil .... 181 peak volts/mil (min 156 - max 191)

The above measurements were taken with alternating current 60 cps and represent the mean of 10 separate measurements on the same specimen.

It has also been found that the extinction voltage at which ionization disappears (by oscilloscope observation) as the stressing voltage is reduced is lower than the ionization starting voltage. This is analogous to the extinction voltage of a gas discharge. A high voltage is needed to knock electrons from their bonds and raise them to higher energy levels, so that corona discharge can take place. After a sufficient number of electrons are set free, a lower voltage will maintain the circuit, but, if the voltage is lowered further, the free electrons will recombine. The difference between corona starting voltage and extinction voltage appears to depend on the type of insulation stressed.

Tests were made on 10 mil Teflon under oil with results as follows:

A. C. ionization starting voltage.......	181.8 peak volts/mil
A. C. ionization extinction voltage.....	166.5 peak volts/mil
D. C. ionization starting voltage.......	226.2 volts/mil
D. C. ionization extinction voltage.....	195.5 volts/mil

It is noted from the above examples that the ionization starting voltage is higher when using D. C. rather than A. C. voltage. No explanation of this difference is offered at this juncture.

Tests were made also on the insulation of wire samples in the form of coil specimen, the construction of which was described in a previous report[5]. These specimens, which are insulated with Silotex (Glass-Silicone), are being aged at 300 degrees Centigrade while periodic measurements of capacitance, dissipation factor, d. c. resistance, temperature, and ionization starting voltage (at 10 microampere deflection on the microammeter circuit) are being recorded. The data, to date, are presented in Figure 23. Similar measurements were made on Formex insulated wire, at 250°C, and the data is presented in Figure 24. It is noted that the characteristics with aging time of the incipient ionization voltage (a-c) follows the trend of the d.c. resistance for the Silotex and Formex insulation. It is conjectured that the initial drop in resistance, or value of incipient ionization voltage, reflects the increased ionic motion and transitional voids being created due to the rapid evaporation of the volatile fractions in the insulation. The later rise in these characteristics reflect reduction in evaporation and increased density of the material. In Formex insulation the dissipation factor varies, as expected, inversely as the resistance; however, its variation with aging time is somewhat different in Silotex. This difference may be explained as follows: The dissipation factor reflects the dielectric losses in the glass and in the silicone varnish. The loss in the glass is constant with aging time while the loss in the varnish is a function in time. As the d-c resistance of the varnish rises, its contribution to the dissipation factor is reduced thus rendering the dissipation factor of Silotex essentially independent of time after the evaporation of the volatile fractions. The initial increase in capacitance is attributed to the relative expansion of the insulation and increase in contact surface. As the volatile contents leave the insulation, shrinkage ensues resulting in decrease in capacitance. It is of interest to note that relative change in capacitance was less in the Silotex insulation owing to the fact that the volatile contents are smaller percentage wise in this insulation than in Formex.

The resistance and corona characteristics for Formex reached a maximum value at the embrittlement point of the material[5]. The corresponding maxima for Silotex does not have significance at this time owing to absence of data on the aging characteristics of Silotex.

SUMMARY

The experience accumulated to date rules out capacitance as a measure of aging. The dissipation factor seems to have significance as a calendar of age for dipolar materials which experience increasing density with age. However, its variations are easily obscured in composite structures of insulating systems. On the other hand, insulation resistance measurements appear to hold greater promise as an index of thermal degradation. As soon on a low voltage, high-resistance bridge is completed, the study of the resistance variation on Teflon and Class B and H insulation will be resumed.

Ionization study has resulted in the development of instrumentation using essentially a resonant circuit. Modifications are intended to increase the sensitivity, amongst which are the replacement of the 7.6 henry swinging choke with a large value honeycomb coil. Provision for changing the resonant frequency of the circuit will be tried with the objective of determining whether ionization currents appear with greater amplitude in a certain frequency band. The microammeter circuit will be improved and standardized so that its deflection can be correlated with the actual quantity of ionization current flowing.

Data presented here is of preliminary nature and it demonstrates the effect of air and type of voltage on incipient ionization, as well as the difference between the starting and extinction voltage. No conclusion can be drawn on the significance of incipient ionization voltage as an index of insulation age until adequate data is obtained on representative dielectric insulation materials and systems.

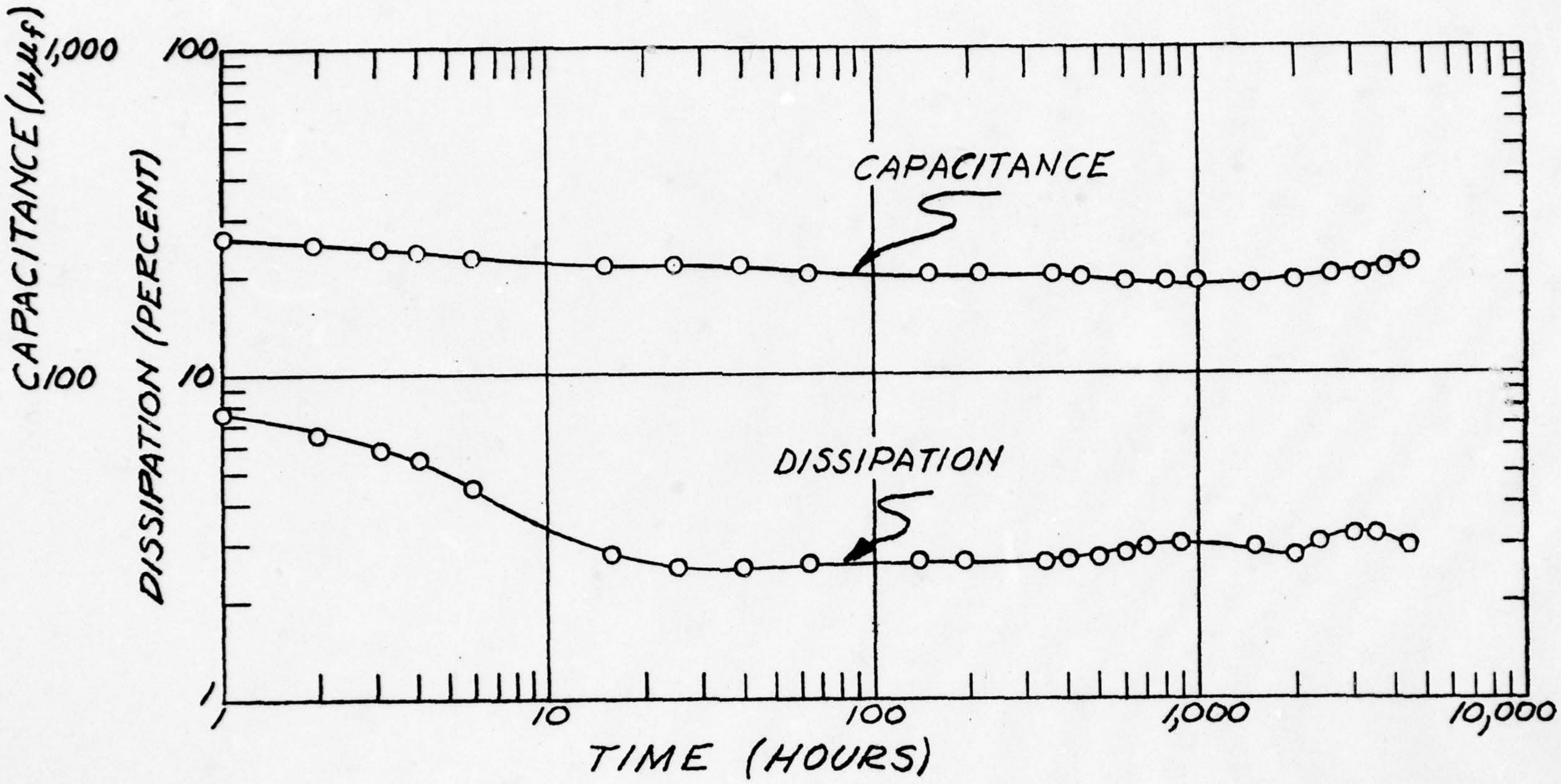

Figure 17. Time variations in capacitance and dissipation of Glass Formex continuously aged at 250°C.

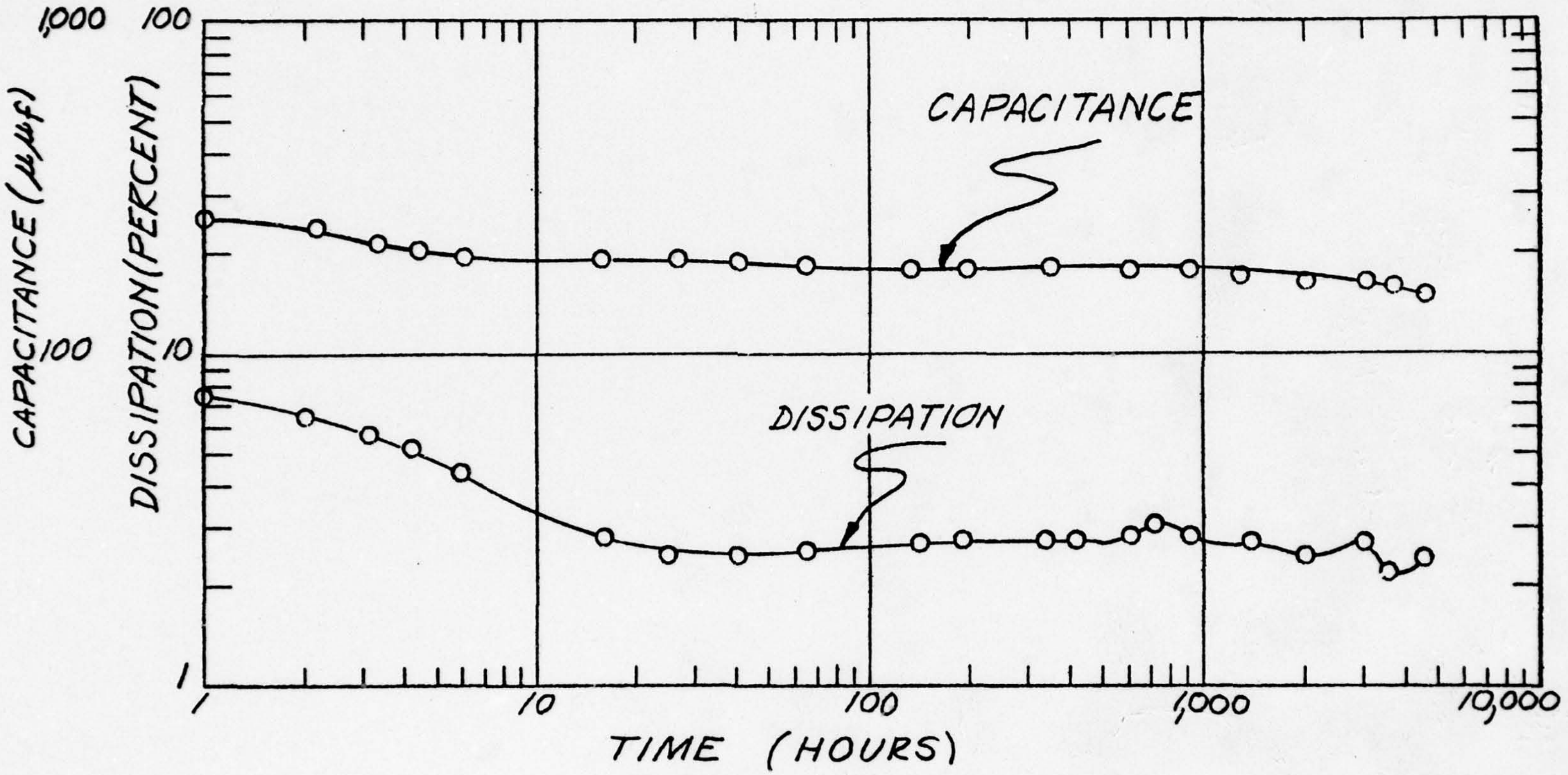

Figure 18. Time variations in capacitance and dissipation of Glass Formex continuously aged at 270°C.

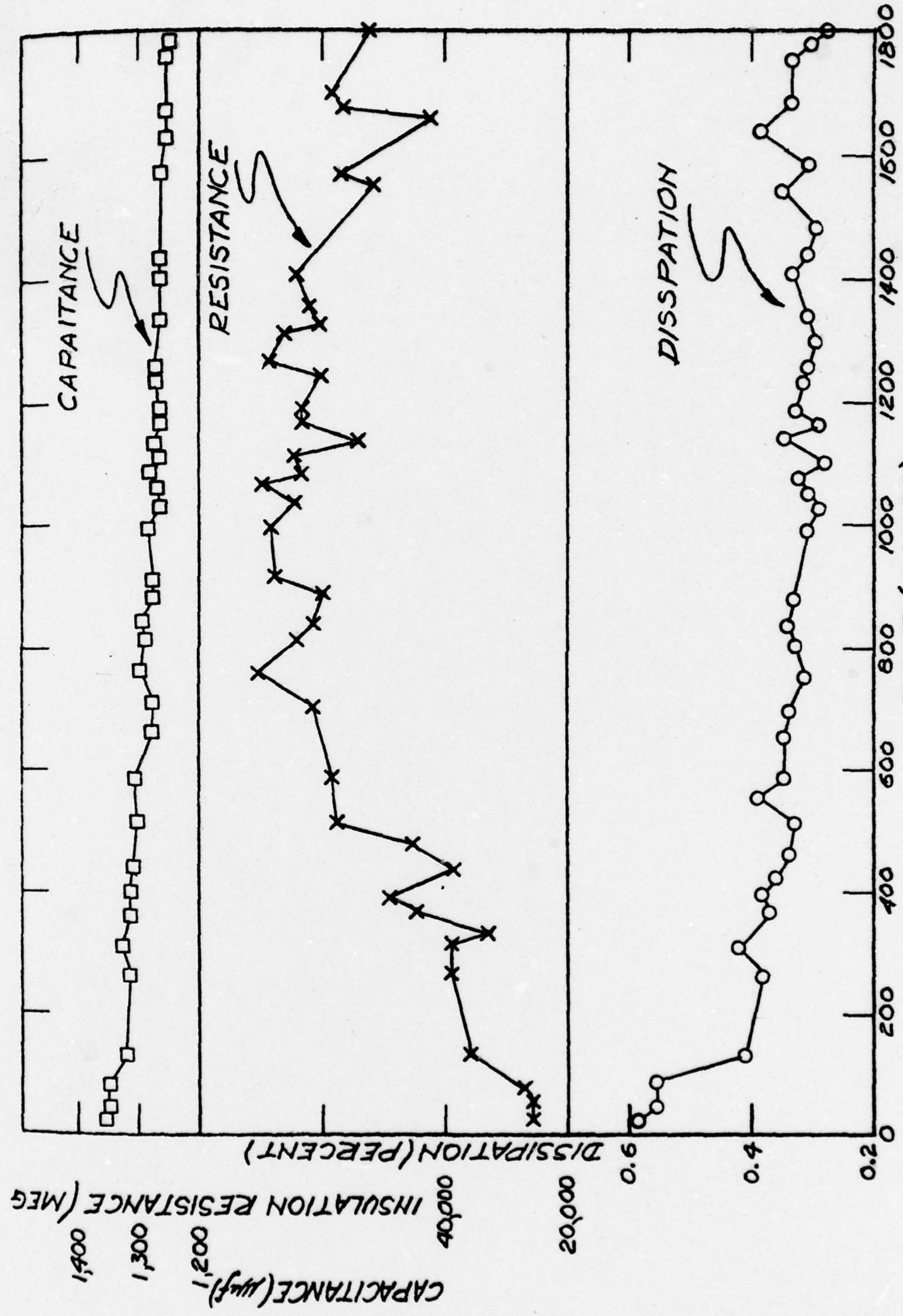

Figure 19. Time variations in capacitance, dissipation and d-c resistance from windings to frame, intermittently aged at 140°C. (Motor No. 2, Formex Insulated, Varnished Treated.)

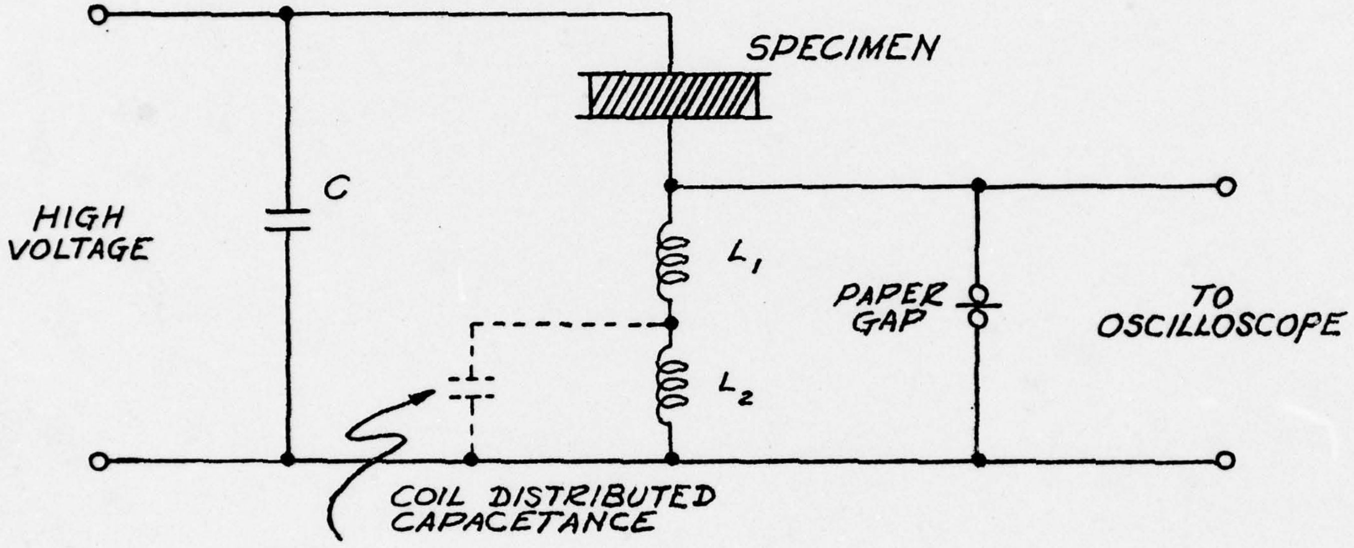

Figure 20. Quinn Circuit for Detection of Ionization Currents.

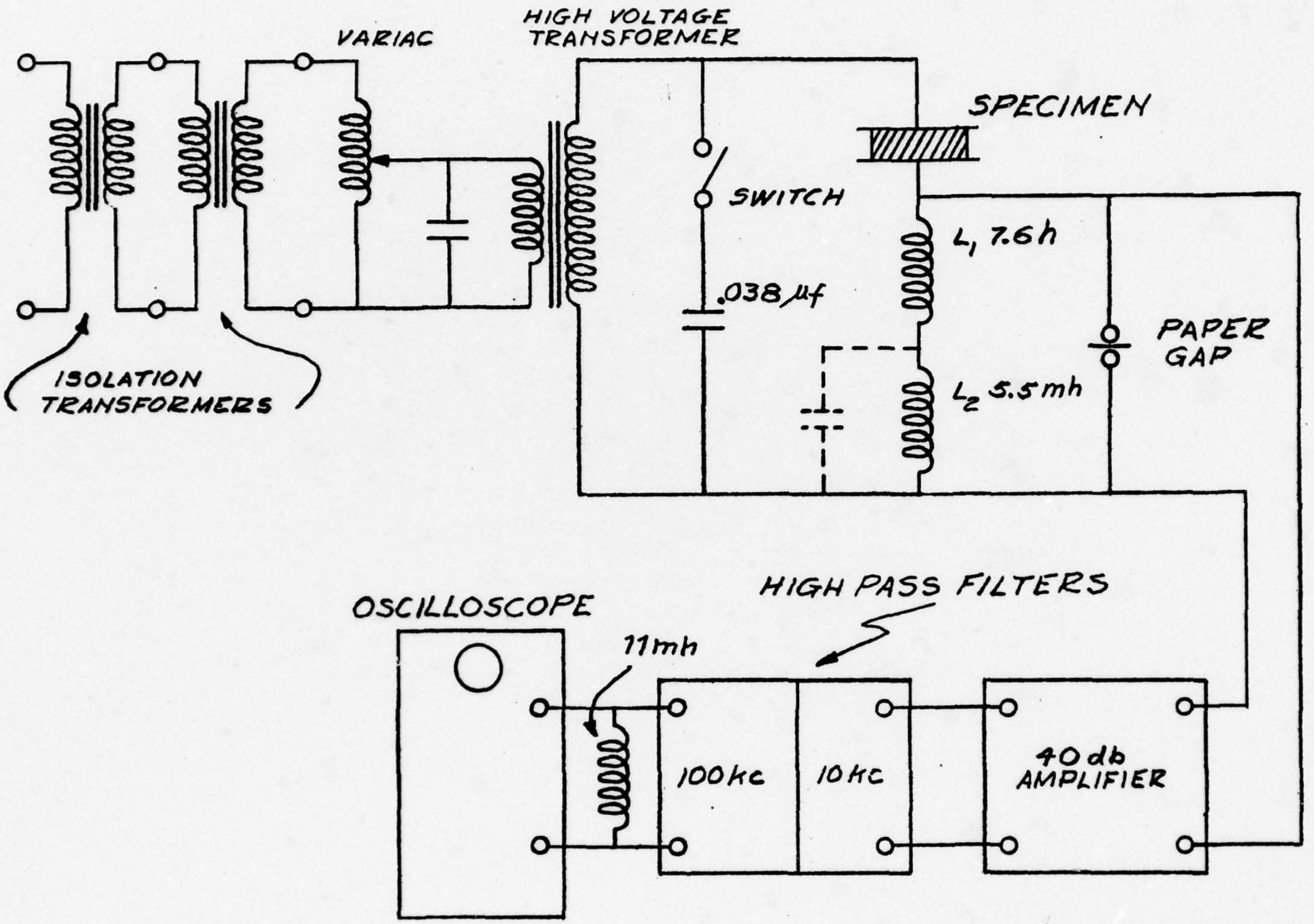

Figure 21. N. R. L. Modified Quinn Circuit for Detection of Ionization Currents.

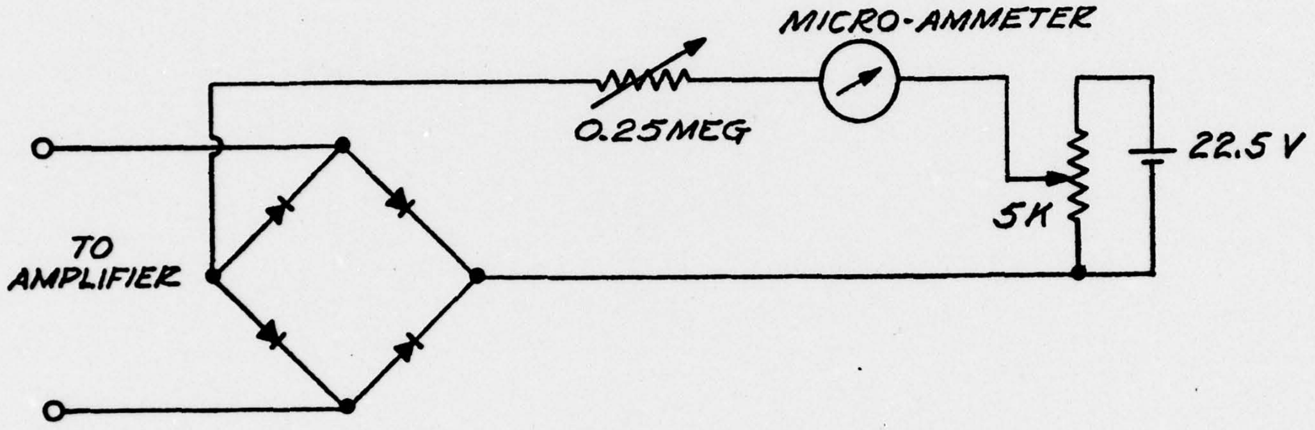

Figure 22. Micro Ammeter Circuit.

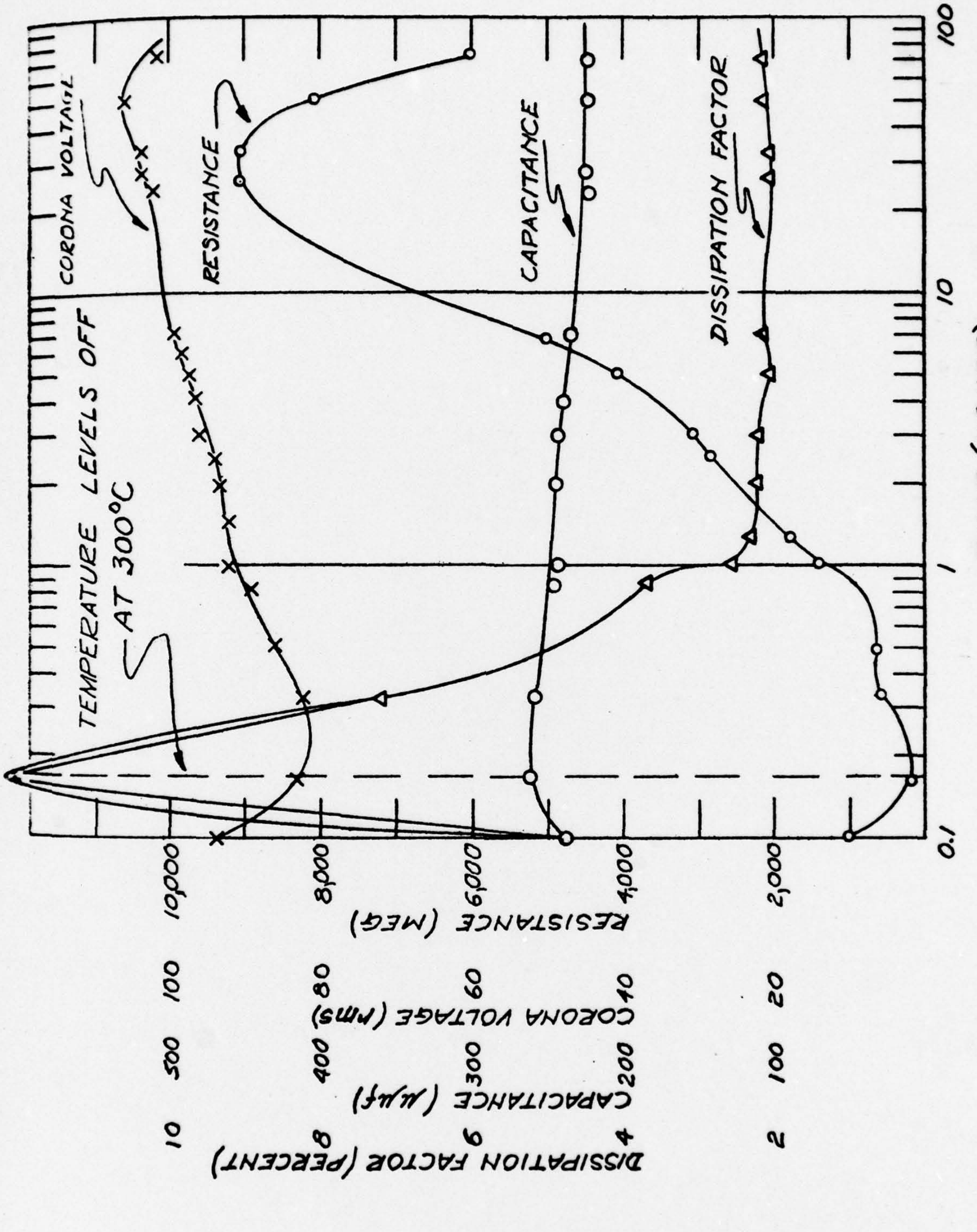

Figure 23. Time variation in capacitance, dissipation, d-c resistance, incipient ionization voltage of Silotex (Glass-Silicone) aged at 300°C.

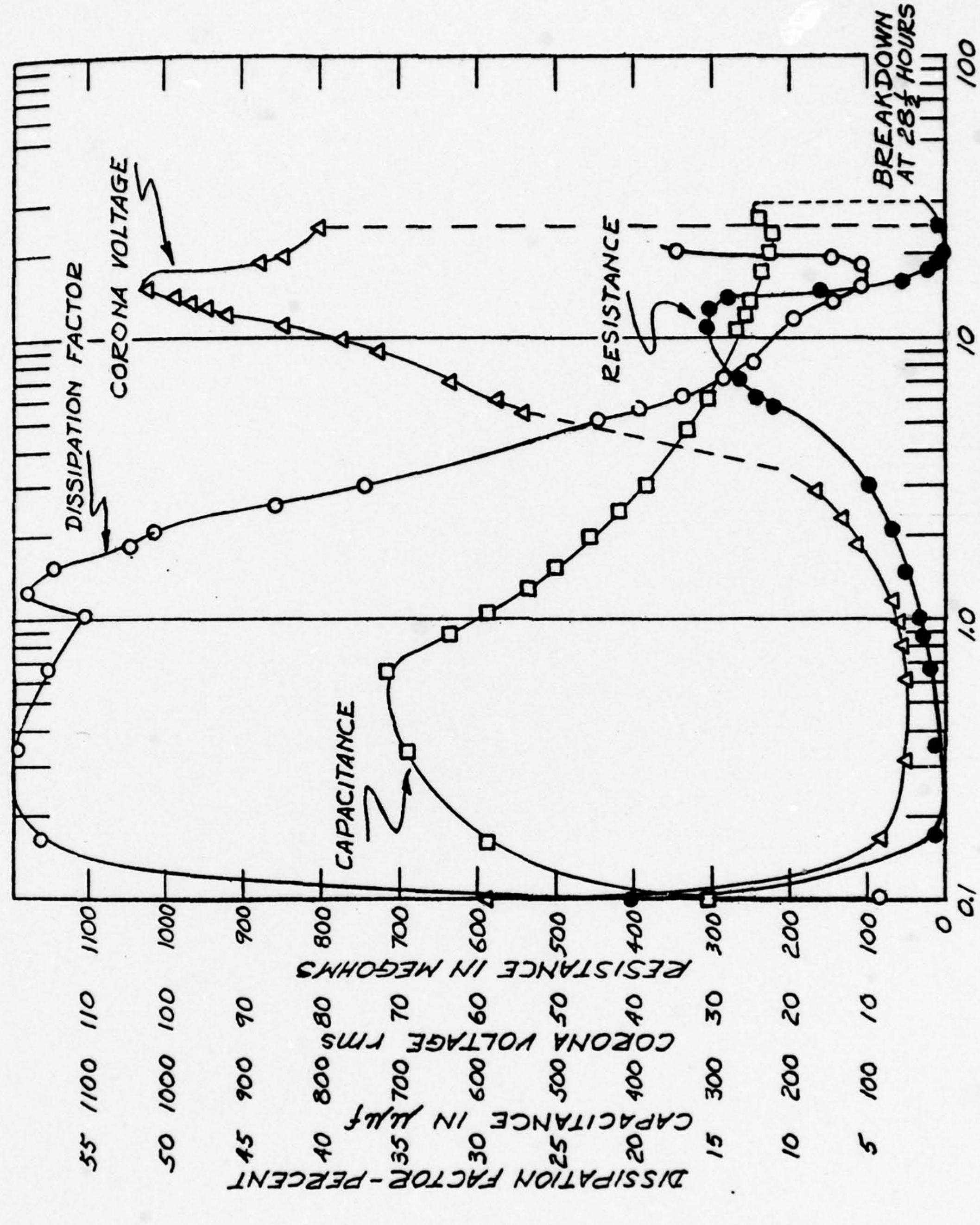

Figure 24. Time variation in capacitance, dissipation, d-c resistance, incipient ionization voltage of Formex insulated wire, aged at 250°C.

EFFECTS OF REPETITIVE VOLTAGE SURGE ON DIELECTRICS

INTRODUCTION

The apparent "fatiguing" or partial damaging of insulation by high voltage impulses is being recognized with mounting interest by the electrical industry. It is suspected that under certain conditions the process of impulse testing itself - as well as the random surges encountered in operation - may seriously shorten the life of the very insulation whose strength the tests are designed to demonstrate. A number of important studies dealing with the effects of steady-state direct and alternating voltages and with the effects of high frequency a-c pulses have been published. However, despite the importance of the subject, very little has been published to date on the phenomenon of "impulse fatigue" produced by a succession of unidirectional high voltage impulses of the type used in the standard impulse testing of power apparatus. A fundamental study of this phenomenon could not only contribute to our basic understanding of the electrical breakdown process, but it could also contribute to our knowledge of the useful properties of some specific insulating materials.

The object of this investigation is to study the effects that repetitive applied voltage impulses at various voltage levels have on the properties of insulating materials. Particular attention is to be directed toward attempting to correlate changes in dielectric strength of a material, as a function of the number of impulses applied, with changes in its other dielectric properties.

This project was undertaken in June, 1952, and is being carried out during the summer months of that and several successive summers. The following work was completed during the summer of 1952.

1) Completion of a literature survey[10].
2) Design and construction of a 360-kv, 1350 watt-second impulse generator.[11]

PROGRESS

The first portion of the summer of 1953 was spent in perfecting the instrumentation to be used with the impulse generator, and in calibrating the generator. A calibration curve for the pair of 10-inch voltage measuring spheres, Figure 25, was determined by the interpolation of AIEE standard curves. Results of measurements made with these spheres checked those obtained with an oscillograph within the ability to calibrate and to read the two devices. An attempt was made to determine the generated voltage in terms of control Variac setting. A preliminary set of measurements with a three-bank generator connection (at a nominal generator rating of 180 KV) demonstrated the existence of a linear relation between the secondary Variac voltage and generator response at a rate of 1 Kv per 1.74 volts output of the variac. Particular attention had to be directed toward the arrangement of grounds and toward the location and shielding of the oscillograph to avoid pick-up of traveling waves and of electromagnetic radiation from the impulse generator. These considerations necessitated the location of the oscillograph at a remote point in a separate room. An aircraft intercommunication system was set up to enable the operators at the two locations to synchronize their activities. Figures 26, 27, and 28 show the generator, the oscillograph, and the associated controls and instrumentation.

It was decided for reasons of convenience to study solid, rather than liquid, dielectrics. Thermoplastic materials attracted particular interest because of the ease with which they could be processed to obtain intimate dielectric-to-electrode contact. To provide a possible clue to the breakdown process, it was further decided to study both polar and nonpolar materials. Polyethylene, a nonpolar thermoplastic solid dielectric, and lucite, a polar thermoplastic solid dielectric, were tentatively selected for this study.

Test Program

The following phases were planned for the test program. Each material would be given the same series of tests. (Impulse waves of the standard 1 1/2 x 40-microsecond form are to be used.)

1. Investigate the relation between crest voltage and number of impulses to produce breakdown. This would yield statistical data on "impulse fatigue".
2. Investigate the effect of repetitive voltage impulses on the following dielectric properties: dissipation factor, dielectric constant and d-c conductivity.
3. Investigate the relation of time between successive impulses to number of impulses to produce breakdown.

4. Investigate relation of rate of voltage rise to number of impulses to produce breakdown.

5. Investigate relation of thickness of dielectric to number of impulses to produce breakdown.

Experimental Equipment

To facilitate performance of the planned tests, the assembly of electrodes and specimen were designed to produce the following: A uniform rectilinear field within the specimen; negligible edge effects; sufficient ratio of cross-sectional area to thickness of specimen that a-c and d-c measurements are possible; and simplicity of construction and assembly.

Experiments revealed that plane parallel electrodes of approximately three square inch cross-sectional area used with specimens of 10-mil thickness would satisfy the measurement criteria. The resulting design is indicated by Figure 29. Each electrode consists of a 2-inch diameter brass cylinder with parallel plane ends spaced at 1.240" ± 0.0001". The end that contacts the specimen is mirror finished and rounded to a 1/4-inch radius at the edges. The holes are provided for mounting. In all essential respects, this design agrees with ASTM Standard D149-44.

Opposing pairs of these electrodes are heated and pressed into opposite surfaces of 1/4-inch thick octagonal specimens of dielectric measuring 3 1/2 inches across. Figure 30 shows the Buehler hydraulic press and the heater-block assembly with a specimen in place. Each heater consists of a cylindrical steel block wrapped with fiber-glass insulated wire through which 60-cycle current is passed. Transite mounting blocks heat-insulate the heaters from the frame of the press. Leveling tables fastened to the electrodes center the specimen during the pressing operation. Clearance is provided between these tables and the electrodes to permit displaced plastic material to flow out as the electrodes sink in. This displaced material forms a collar around each electrode that provides mechanical strength, helps to seal out contaminants from the interface between dielectric and electrode, and reduces the occurrence of surface discharges around the electrode during test. Pressures are indicated by a hydraulic gauge on the press, and temperatures of electrodes are measured with a "Pyrocon" thermocouple indicator.

Experiments show that electrodes heated to 240°F can be successfully sunk into a specimen of polyethylene under a pressure of 300 pounds per square inch in 4 minutes. Too low a pressure, or too high a temperature results in the formation of bubbles in the specimen. A sensitive Model 382 Ames distance gauge is used to measure the spacing between electrodes. Clamps preserve the proper spacing during removal of the specimen from the press. Figure 31 shows a specimen blank, a specimen immediately after removal from the press, with leveling tables still in place, a completed specimen, and a specimen with electrodes removed following test. The rods in the foreground, when inserted into the holes in the sides of the electrodes and the heater blocks, serve as wrenches for unscrewing the heater from the electrode.

As shown in Figure 32, the specimen is mounted for test in a tank of oil on an insulating stand to which the high voltage and ground leads are brought. The oil reduces corona at the exposed surfaces of the electrodes and prevents flashover of the specimen during test.

Results

The following data have been obtained to date. All impulses to a given specimen were of the same magnitude and were applied at 10-second intervals until failure occurred.

Thickness in Mils	Number of Impulses	Volts per Mil	Remarks
9.5	30	4820	
9.0	111	4930	
8.7	25	5000	
16.2	28	5000	
21.0	79	5000	
21.8	21	5000	
23.2	77	5000	
21.5	13	5500	
21.0	250 +	2880	Specimen did not fail: test discontinued.
19.2	1	5500	

Considerably more test data are needed before any conclusions can be drawn, although the occurrence of "impulse fatigue" is clearly evident. Several cases where breakdown occurred at a low number of volts per mil were found to be due to the existence of bubbles in the specimen - the result of faulty processing - and are not included in the above tabulation.

SUMMARY

Completion of the projected tests, followed by an attempt at theoretical interpretation of the experimental results, is planned for the future. Depending on the findings and their interpretations, it may be desirable to repeat some of the experimental procedures with other solids.

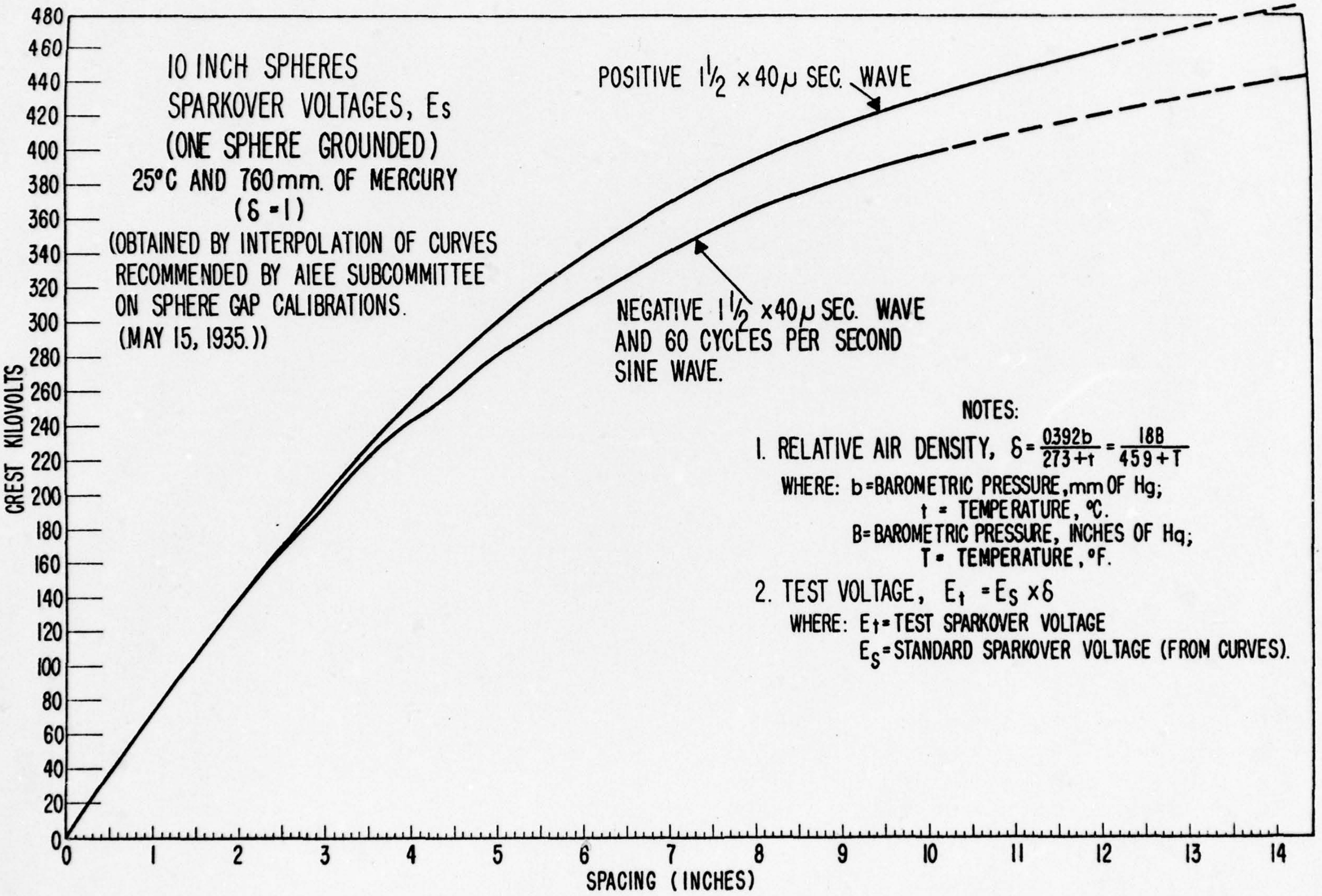

Figure 25. 10-Inch Sphere Gap Calibration Curves.

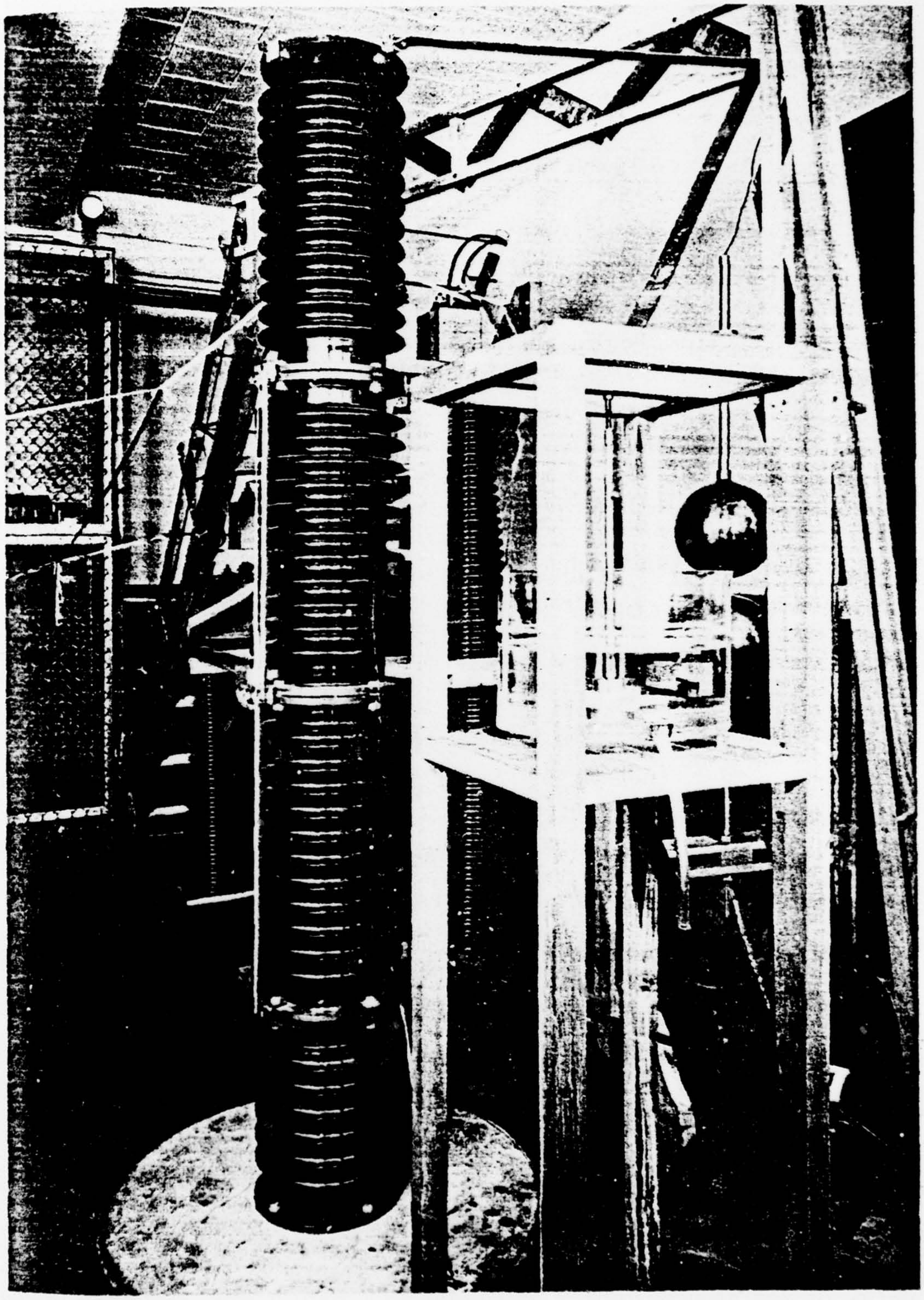

Figure 26. The output end of the NRL 360-kv 1350 watt-second impulse generator.

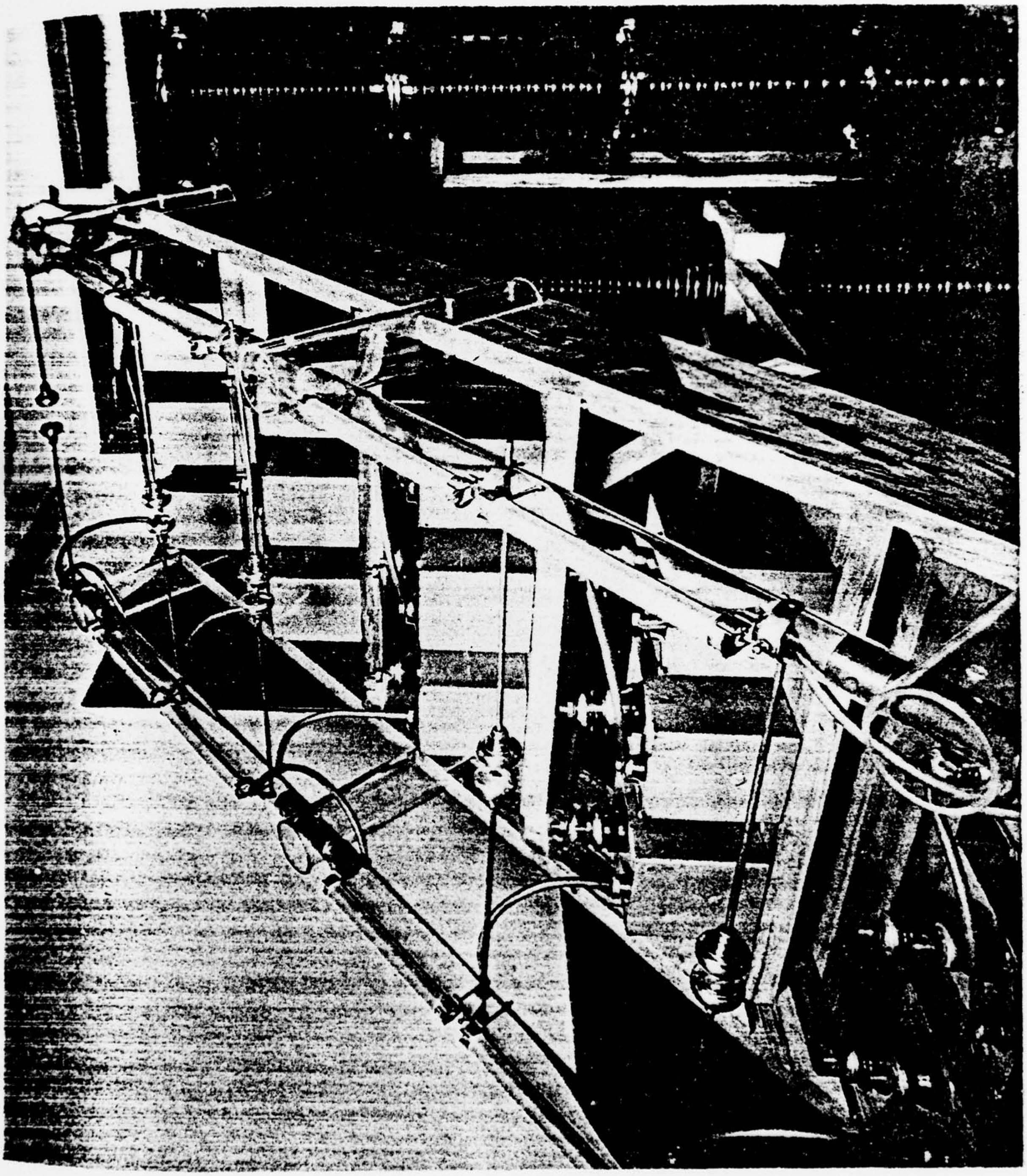

Figure 27. The capacitor bank of the NRL impulse generator.

Figure 28. Impulse generator control area and the oscillograph.

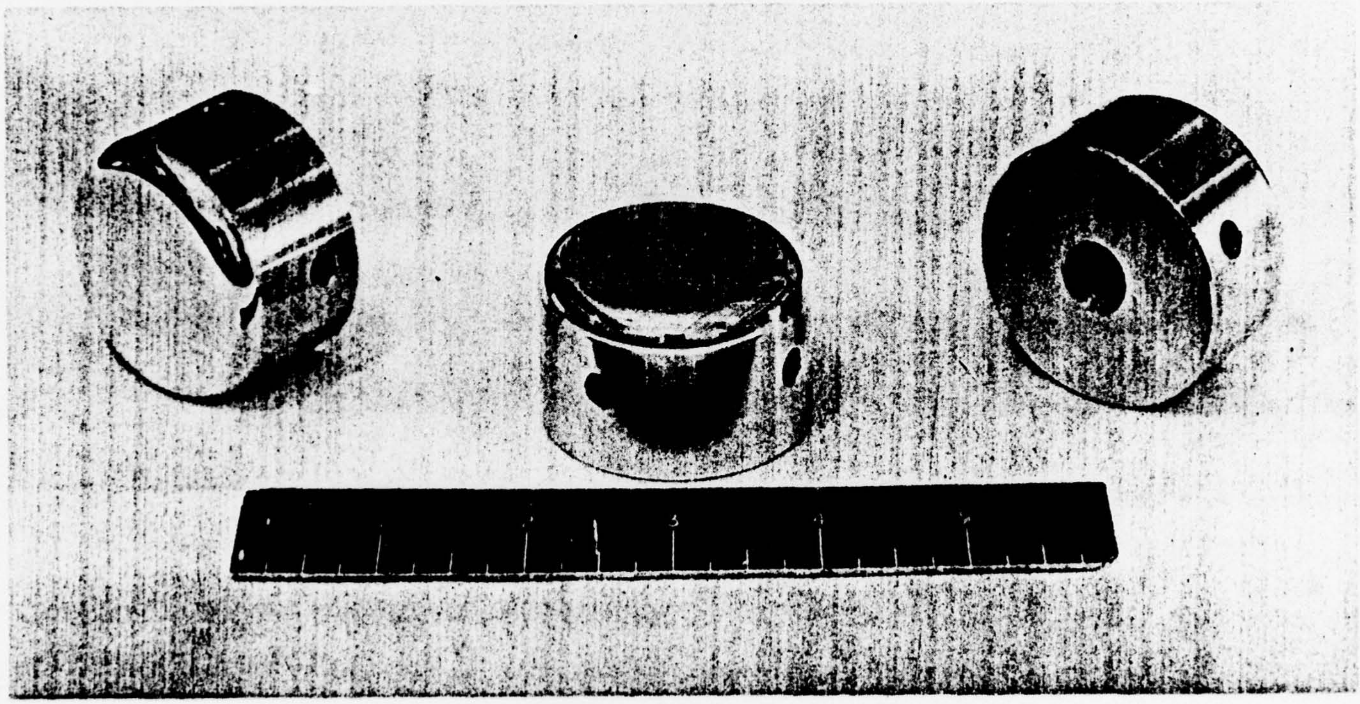

Figure 29. Highly polished brass electrodes.

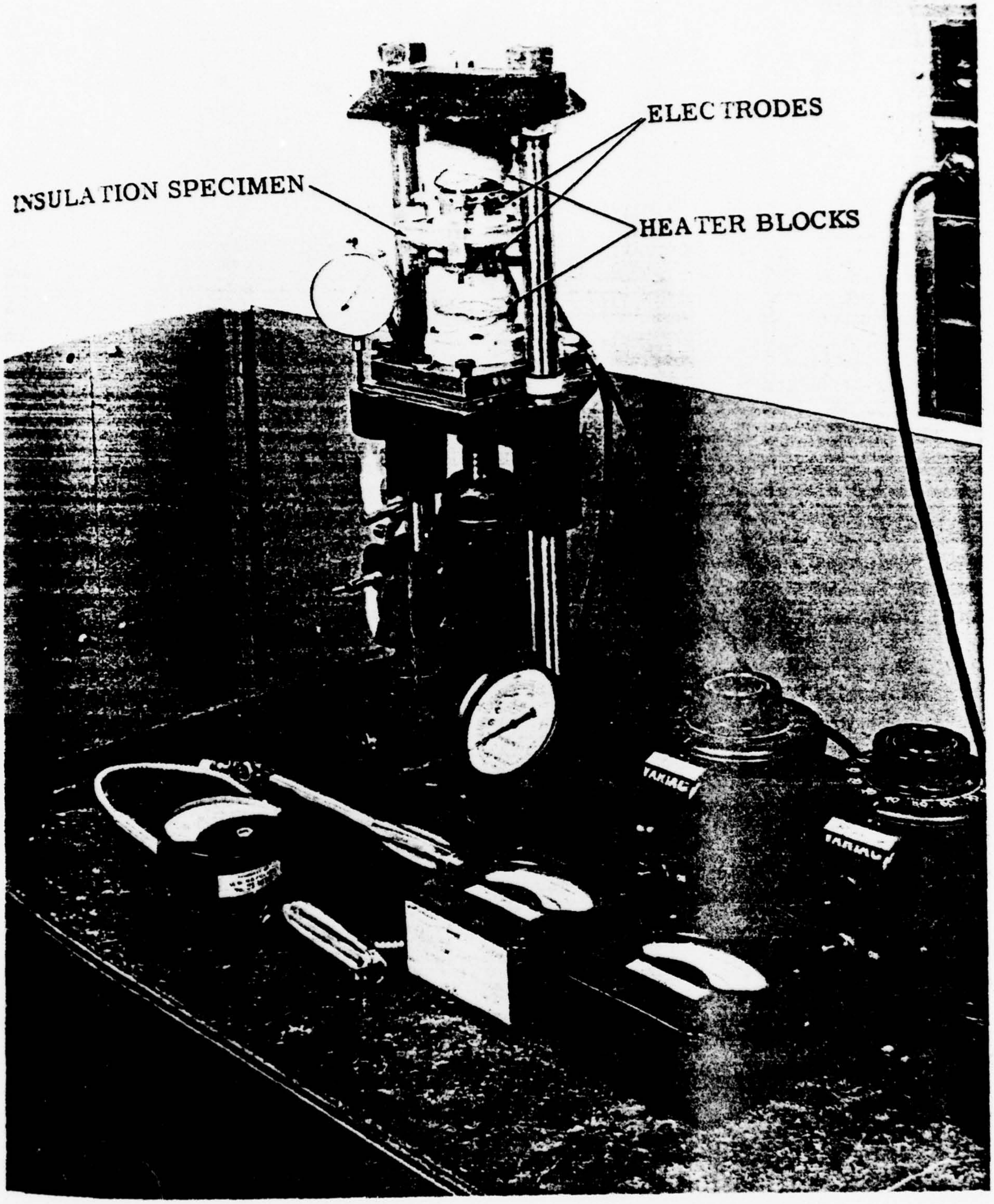

Figure 30. Hydraulic press, with heater blocks, electrodes, and specimen in place.

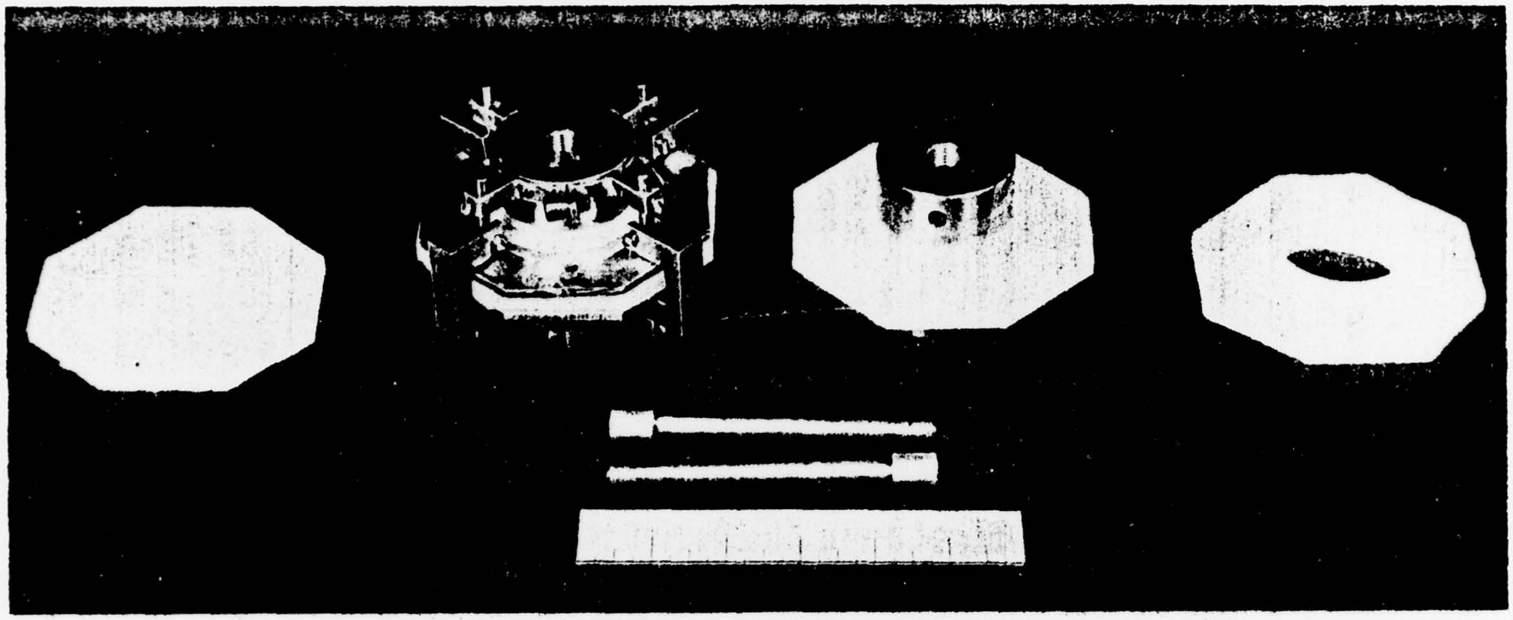

Figure 31. Polyethylene specimen blank, damped specimen, finished specimen and tested specimen. Rods are wrenches used in removing specimen from press.

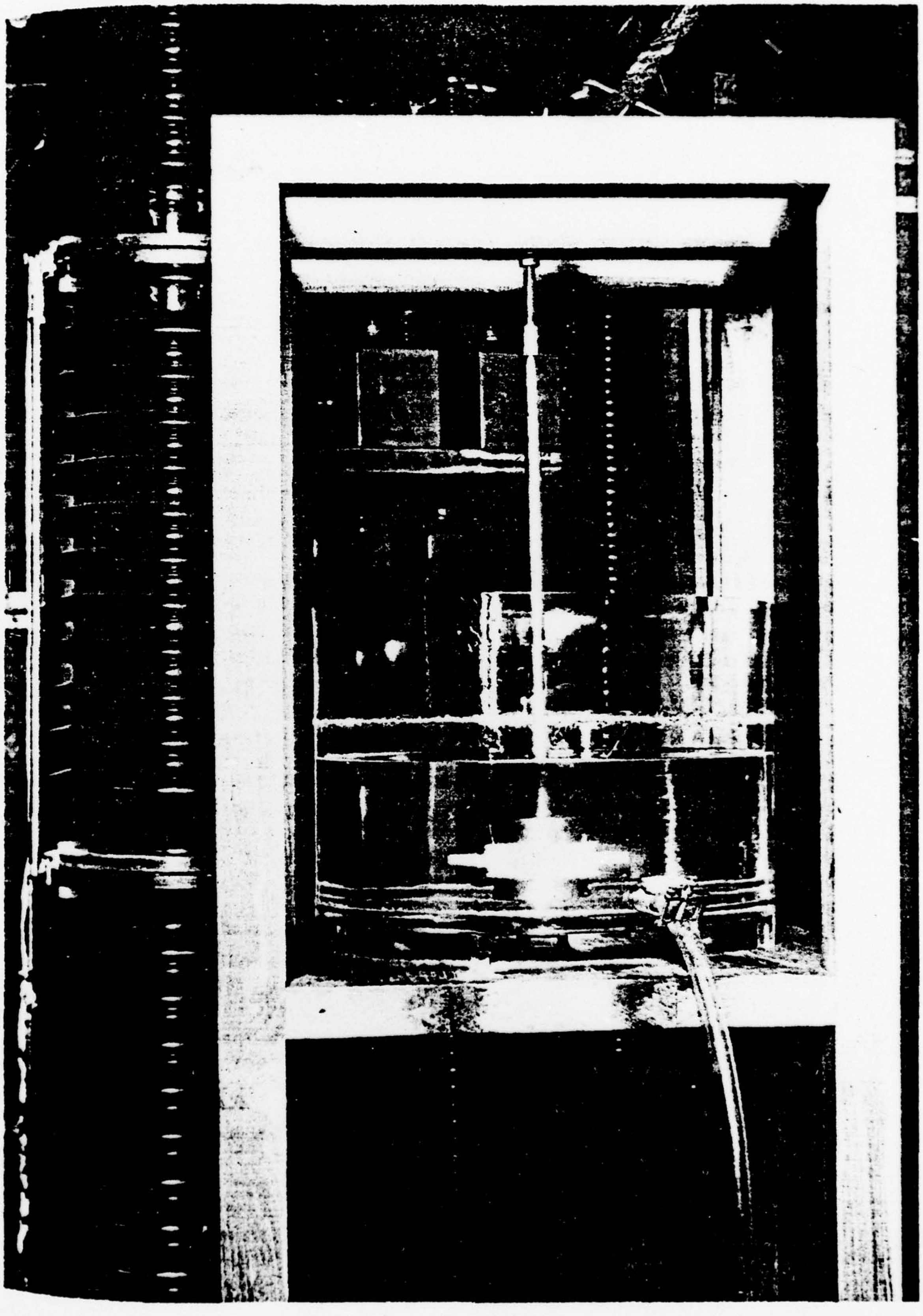

Figure 32. Specimen in oil-filled test tank.

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By John Cybulski.

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