NPS ARCHIVE
1969
STROUSE, R.

AN EXPERIMENTAL INVESTIGATION OF THE MASS DISTRIBUTION FROM THE EXHAUST OF A COAXIAL PLASMA ACCELERATOR

Robert Dale Strouse

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5101

United States
Naval Postgraduate School

THESIS

AN EXPERIMENTAL INVESTIGATION OF THE MASS DISTRIBUTION FROM THE EXHAUST OF A COAXIAL PLASMA ACCELERATOR

by

Robert Dale Strouse

June 1969

This document has been approved for public release and sale; its distribution is unlimited.

T133499

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93943-5002

An Experimental Investigation of the Mass Distribution from the Exhaust of a Coaxial Plasma Accelerator

by

Robert Dale Strouse
Second Lieutenant, United States Marine Corps
B. S., United States Naval Academy, 1968

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN
AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1969

NPS ARCHIVE
1969
STROUSE, R

ABSTRACT

Investigations were conducted on the mass distribution of the exhaust of a coaxial plasma accelerator in order to gain insight into the manner by which the fuel (gold) is ionized and accelerated.

Tests were conducted using both annular sections of gold foil and single strands of gold wire. Both types of runs showed a non-uniform angular distribution with one or more well defined peaks. The similarity between the distributions leads to the probable conclusion that the foil, rather than undergoing uniform ionization around the annulus, is actually ionizing at discreet "spokes" about its periphery.

Experiments conducted with gold foil involved varying the distance from the accelerator to the collector. A fairly uniform dispersion of gold plasma was observed as collector distance increased.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure

Figure

ACKNOWLEDGEMENTS

The author is indebted to Professor D. C. Wooten of the Aeronautics Department for his assistance throughout the project. The author also wishes to express his appreciation to Messers Theodore Dunton, Robert Besel, and Dana Maberry, and the remainder of the technical staff of the Department of Aeronautics for their assistance on the many technical problems encountered in the course of the research included in this paper.

I. INTRODUCTION

A. BACKGROUND

Plasma accelerators provide a means for making detailed studies in magnetohydrodynamics, a field of interest in many diverse scientific disciplines. Astrophysicists, for example, are interested in the field from the point of view of explaining the behavior of celestial bodies and their magnetic and electrical properties [3]. The engineer is perhaps more interested in the direct applications of the plasma accelerator rather than its use as a tool in studying electromagnetic phenomena. Among these applications are shock wave generators and space propulsion units. The latter of these two applications, while under extensive study, has not yet proven feasible, due to low efficiencies of systems thus far developed [6].

Plasma accelerators depend upon the action of Lorentz forces for their operation [1], as illustrated in Fig. 1. The magnetic field due to the current flowing through the electrodes interacts with the current flowing through the plasma, and produces the familair $\vec{F}=\vec{J}\times\vec{B}$ reaction, with the force $(\vec{F})$ driving the plasma out the barrel of the accelerator. Secondary effects due to current loops (Hall currents) within the plasma are relatively small and require sensitive and sophisticated instrumentation for investigation [7]. These secondary effects will not be dealt with in the remainder of this paper.

The plasma accelerator used in these experiments had previously undergone only two investigations: velocity measurements [2], and determination of environmental pressure effects on gold deposition [9]. The latter tests used a 2.4 inch I.D. cylindrical collector placed concentric to the plasma accelerator, and extending to near the top of the bell jar. These experiments produced two important conclusions: The distribution of gold plasma outside the accelerator is not angularly uniform, and pressure effects were extremely small over the range of pressures, 50×10^{-3} mm. Hg. to 50×10^{-5} mm. Hg., investigated. All previous experiments were done with gold foil.

The non-uniform angular distribution suggested that the gold foil was ionizing only locally at one or two places, so that rather than a uniform "doughnut" of plasma, only one or more "spokes" were produced. In order to test the spoke model, gold wire was employed. Runs made with the wire could be compared to runs made with foil to determine the validity of the model.

Also of interest is the diffusion pattern of the plasma leaving the accelerator. By varying the distance of the collector (described in part II) from the barrel of the accelerator, and noting the pattern of the deposited plasma at varying distances, a measurement of the exhaust diffusion may be found.

B. DESCRIPTION OF APPARATUS

The coaxial plasma accelerator system used consisted of the following major components: vacuum system, high voltage power supply, high voltage capacitor and firing circuits, triggering circuits, and accelerator electrodes, together with the necessary instrumentation for monitoring and controlling the apparatus.

1. Vacuum System

The vacuum system (Figs. 2 and 3) consisted of two major parts. The first, a Welch 1397B vacuum pump and associated values, was used to rough the system down to a pressure of about ten microns of mercury. The second was a Welch 1402B fore pump with a Veeco combination diffusion pump, baffle, and nitrogen cold trap. This high vacuum system was capable of achieving pressures of 1×10^{-4} mm. Hg. without the liquid nitrogen cold trap. Approximately an order of magnitude improvement was realized with the use of the cold trap. Extensive testing with a mass spectrometer type leak detector indicated that no leaks were present. Vacuum limitations would therefore appear to be due to outgassing of the vacuum system.

Vacuum measurements were made with a Veeco DV1M thermocouple guage at pressures above 1 micron of mercury. For lower pressures, an ionization guage tube was used. The vacuum instrumentation was monitored and controlled from a Veeco RG-31X control panel. (Figs. 4 and 5)

2. High Voltage System

The high voltage power supply (Fig. 6) used to charge the plasma accelerator capacitor was a 40KV unit controlled and monitored from a control panel (Fig. 7) on the front of the unit. Charging was through a colenoid operated knife switch and a three megohm resistor. A microameter in series with a 600 megohm resistor was connected across the capacitor, so capacitor voltage could be read. A calibration curve (Fig. 22) of capacitor voltage as a function of microameter reading was obtained using a high voltage, Sensitive Research Corp., 1% full scale electrostatic voltmeter. It was found to differ from previous calibration [2] by 15%.

The unit was equipped with a Jennings high voltage relay which, when opened, grounded the capacitor through a one megohm high voltage resistor. The relay could be used to abort a shot or bleed residual capacitor voltage after firing.

3. High Voltage Capacitor and Firing Circuits

The gold foil and wire were ionized in the plasma accelerator by the discharge of an Axel 6.4 microfarad low inductance capacitor at 15,000 volts. Four GE 7703 ignitrons, rated at 20KV and 100,000 amps. peak current provided the switching between the capacitor and the electrodes of the accelerator. (Fig. 8)

4. <u>Triggering Circuits</u>

The ignitrons were triggered by a 6268 thyratron in the pulser circuit (Fig. 9). The pulser circuit was triggered by a 120 volt pulse provided by a 2021 thyratron in a triggering circuit (Fig. 10). This latter circuit was also used to trigger an image converter camera and oscilloscope.

5. <u>Accelerator Electrodes</u>

The coaxial copper electrodes (Fig. 8) are the basic components of the plasma accelerator. The center electrode, a 1 inch diameter solid cylinder, is separated from the capacitor by the ignitrons, as mentioned above. The outer electrode, a 1.5 inch I.D. copper tube, is connected directly to ground. Golf foil or wire placed across the gap between the electrodes is ionized upon capacitor discharge.

The electrodes were not perfectly concentric, the axes being approximately .03 inches apart at the extreme end. In order to assure reproducible results, scribe marks were made on the electrodes so they could be oriented the same way for each firing.

6. <u>Photographic Apparatus</u>

In order to photograph the actual firing of the plasma accelerator, an Abtronics Model 1 image converter camera was employed. The camera (Fig. 11) was mounted so as to look down the barrel of the accelerator.

The camera has four shutter tubes, each with its own circuit, allowing independent triggering at any desired delay. Due to the camera's lack of accuracy in the range of small time delays employed (about 2 μsec. between shots) the camera was monitored on an oscilloscope (Figs. 12 and 13). The oscilloscope and camera were both triggered by the same circuit used to fire the thyratron in the main capacitor firing circuit. The camera was equipped with a monitor output which provided a signal each time one of the camera circuits fired. This output was used for the oscilloscope input.

II. EXPERIMENTAL PROCEDURE

A. PLASMA ACCELERATOR PROCEDURE

The basic procedures employed in these experiments were developed by Brumwell [2] and Smith [9] in previous experiments with the same apparatus. These procedures involve the firing of the plasma accelerator and then collecting the discharged plasma on aluminum foil collectors for analysis by means of radioisotope tracing.

For the firings involving the gold wire (runs 1-12), the collectors were 1.5 inch diameter aluminum foil disks mounted in a plexiglass cap placed over the end of the electrodes. The collector itself was .5 inches from the end of the accelerator. The gold wire was placed across the .25 inch gap between the electrodes (Fig. 8) at the same place for every firing. This point was used for angular reference. After firing, the collector disk was removed, sprayed with clear, acrylic lacquer to prevent loss or movement of the deposited gold, and then cut into eight, equal, pie-shaped pieces. The centerline of the first piece corresponded to the zero degree reference, with succeeding pieces being cut every 45 degrees in a counterclockwise direction. Six runs were made with each of the two sizes of wire, .020-inch diameter and .005-inch diameter. Pressures were varied from 1.0 to 8.0×10^{-4} mm. Hg.

For the firings involving gold foil (runs 13-17) the collector (Fig. 3) was a seven inch diameter aluminum foil disk supported on a metal stand. The distance from the collector to the end of the accelerator was varied from two to ten inches in two inch increments. After firing, the collector was removed and lacquered as before, and samples were cut from the collector with a steel tool (Fig. 15). The samples were circular, with a diameter of .73 inches. The first sample was cut from the center of the collector, with subsequent samples cut from concentric circles inscribed at 3/4 inch intervals from the center of the collector. Each sample was placed in a paper folder properly marked with the circle from which it was cut and its angular position from a fixed reference. For example, the sample cut on circle "O" would be the center sample, and would be labeled "O-O". A sample cut from circle "2" (i.e., 1-1/2 inches from collector center), 45 degrees from the fixed reference would be labeled "2-45." This labeling system was carried over to the data tables used in this report. Runs 13-17 were made at a pressure of 5×10^{-4} mm. Hg. All runs were made with a capacitor voltage of 15KV.

B. RADIOISOTOPE TRACER TECHNIQUE

The tracer technique employed in these experiments was the comparator method [5]. In this method, a sample of previously determined mass is irradiated together with samples of unknown mass. Assuming that all samples receive the same radiation, the unknown mass may be determined by means of the following equation:

$$\frac{\text{activity of known mass}}{\text{known mass}} = \frac{\text{activity of unknown mass}}{\text{unknown mass}} \qquad (1)$$

The activities are determined by means of a scintillation counter.

Irradiation was carried out in the Aerojet-General Nucleonics AGN-201 nuclear reactor at the Naval Postgraduate School Reactor Facility. Samples were introduced into the reactor core by means of a hollow plastic tube (Fig. 14) with the samples at one end between polyethylene plugs. Irradiation was accomplished with a power setting of 300 watts for a period of ten minutes. Gold 197 was irradiated, undergoing the following reaction:

$$n + Au^{197} \rightarrow Au^{198*} \rightarrow Au^{198} + \gamma \qquad (2)$$

That is, the gold nicleus captures a neutron, producing an excited nucleus (*) which decays by emitting a gamma photon, which is then detected by the scintillation counter. The scintillation counter [4] detects the gamma photons by means of a luninescent material (in this case sodium iodide) which converts the energy of a striking gamma photon into photons at or near the level of visible light. These "flashes of lights" are detected by a photomultiplier tube, which converts them into electrical pulses, which are then amplified and counted. The counting unit used provided for the oscilloscope display of the counting process, with the vertical scale a measure of the number of counts and the horizontal scale indicating the channel being counted. Up to 512 channels could be displayed, each representing a particular energy level of gamma photons being detected. Using an irradiated gold sample, a rapid pulse height analysis was possible using the oscilloscope, and the proper channels for detecting gold could be easily determined. Sixteen channels on either side of .411 mev. were found to completely encompass the gold photopeak. In addition to the oscilloscope display, the unit was also equipped with a memory, used to store the counts in each channel, and a selective integrator which, when the preset counting time had expired, could be made to sum the total number of counts in a selected band of channels, in this case the 32 channel band centered at the .411 mev. energy level. Once the integration was complete, the total number of counts, together with the counts for each channel, were printed out by means of a teletype unit. The total counts, summed by the integrator, then divided by counting time, gave the sample activity in counts/min.

Runs 1-13, containing collector foils of all plasma accelerator firings using gold wire, were irradiated together. Four samples of known gold mass were included. These samples consisted of a known mass of gold foil, weighed on an electrical balance, and placed on a plain piece of aluminum foil the same as the unknown sample pieces. The small gold sample adhered to the aluminum after the former was sprayed with acrylic lacquer. Also included were plain aluminum foil samples, in order to accurately determine background count. Counts of aluminum and gold samples were made at various times during the counting process. Using the control sample data, equation (1) may be slightly altered as follows:

$$\frac{(\text{activity of known mass} - \text{background activity})}{\text{known mass}} = \frac{(\text{activity of unknown mass} - \text{background activity})}{\text{unknown mass}} \quad (3)$$

The ratio on the left hand side of equation (3) was called by control factor and was plotted as a function of time (Figs. 23 and 24). Thus, rather than counting the control activities each time an unknown sample was counted, the control samples were counted only frequencly enough to obtain the plots of Figs. 23 and 24, and the control factor could be taken from the graph at any desired time.

It was found that the background count was random. This was due to two factors. First, about 2/3 of the background activity was not due to the aluminum control samples, but was random noise, recordable even when no aluminum sample was present. Secondly, due to the short half-life of aluminum and other impurities in the foil, most of the nuclides had already decayed, that part still active representing the relatively flat portion of the exponential decay curve, and not subject to much change over the period of several hours during which counting took place. Therefore, an average value (164 counts/min.) was assumed for the background count and was subtracted from the sample activities. The sample activities of the data tables represent observed activity minus background activity.

Runs 13-17 were irradiated and counted in the same manner as runs 1-12, with their own set of control samples.

Counting time varied from 1 to 4 minutes, depending upon sample activity, the length of time being chosen so as to insure a total of about 1000 counts. The number of counts observed for a given sample activity is a normally distributed random variable with variance, $\sigma = N^{1/2}$, where N is the number of counts [5]. With 1000 counts, the variance is 31.6 or 3.16% of the total count.

C. IMAGE CONVERTER CAMERA PROCEDURE

In order to photograph the plasma moving through the accelerator, the image converter camera was mounted above the bell jar, either on the wooden stand, as in Fig. 11, or directly on the flat plexiglass top. The advantage of the higher mounting was that it would eliminate some of the paralax due to the fact that each of the four camera lenses was off the axis of the electrodes. Pictures taken from the higher position were too small for reproduction (about 1/8 inch in diameter) and so do not appear in this paper. The effect of paralax does not appear to have influenced the pictures taken at the lower camera position (Figs. 16 and 17).

Figs. 16 and 17 are photographs of gold foil and .005 in. gold wire, respectively, after ionization. The sequence of photographs is upper right, lower right, upper left, lower left, with approximately 2 μsec. between photographs. (Camera circuit number 3 failed to function for the series of photographs of Fig. 17.)

III. RESULTS AND CONCLUSIONS

Results of the radioisotope tracer analyses of the plasma spattered aluminum collectors are presented in graphical form in Figs. 25 - 46, with sample data in tables 1 and 2. Each gold distribution plot has been normalized with respect to the total mass of gold collected in its respective run.

Figures 25 - 29 are plots of gold distribution as a function of distance from collector center, where gold foil was used in the accelerator, and the collector distance was varied from two to ten inches by means of an adjustable stand (Fig. 3). At a distance of two inches (Fig. 25) most of the gold is distributed in a very narrow band centered at 3/4 in. from the collector center. This band corresponds in position to the annulus between the accelerator electrodes. As distance from the end of the accelerator increases (Figs. 26 - 29) the peak flattens out, indicating diffusion of the plasma inward and outward from the original annulus.

Figures 30 - 34 are plots of the same shots mentioned above, with angular distance from a fixed reference replacing distance from collector center as the abscissa. Compare these graphs with Figs. 35-46, the plots of gold distribution for runs using wire. The similarity in shape between the two sets of curves definitely lends credence to the spoke model describing the manner in which the gold foil behaves in the accelerator. In both cases, there are notable peaks in the distribution. For the runs made with wire a peak at the zero degree point, the location of the placement of the wire before firing, would certainly not be unexpected. However, for a number of runs made with wire, more than one peak occurs, indicating that the wire has somehow been separated into two or more large plasma slugs. This multiple peak phenomenon also appears in runs made with foil, indicating that the foil may have only one spoke. That is, only one point around the periphery of the gold foil may be actually ionized, even though more than one peak is observed in the angular distribution.

The similarity between photographs taken of the foil and wire after ionization (Figs. 16 and 17) also tend to substantiate the spoke model for foil ionization. In both cases, there are regions of almost total darkness (little or no plasma present).

For the foil disk, a total of 15.55 mg. of gold foil (thickness .00005 in.) were available for ionization. For the .005-in. diameter wire, 1.553 mg. were available, and for the .020-in. diameter wire, 24.8 mg. were available. In the runs with the foil disks, 6.82 to 14.98 mg. of foil were collected in each run. For the .005 inch diameter wire, .02065 to .0575 mg. were collected, and for the .020-inch diameter .7261 to 1.1692 mg. Converting these figures to percentages, 44% to 96% of original mass was collected for the foil, while 1.29% to 3.7% of the .005-inch wire, and 2.9% to 4.9%

of the .020-inch wire were collected. A possible explanation of this phenomenon can be found by examining the collectors through a microscope. The collectors used in the runs involving gold foil contained large numbers of circular gold particles .001 to .003 inches in diameter. These particles were photographed under 10 power magnification (Fig. 21). On the scale appearing across the photographs, each large division marked by numerals represents .01 inches. While too large to have been ionized plasma, these particles were probably "pulled along" by the charged plasma particles. The gold foil, only .00005-inch thick, could be broken into many tiny particles in a very short period. The collectors containing the deposited wire, on the other hand, showed surface discoloration after a shot (Figs. 19 and 20), with a number of particles smaller than .0005-inches across observed in the case of the .020-inch diameter wire. It may be concluded then, that the relatively thick wire is unable to disintegrate, as does the foil, and thus only ionized gold or extremely small non-ionized particles are accelerated, while the remaining wire breaks up into pieces too large to be pulled along by the charged plasma.

The relatively high percentages of gold foil collected (44-96%) contrasts sharply to data collected by Smith [9]. Using both the circular foil collector described previously, together with a horizontal cap-like collector at its top, he was able to collect only about 12-14%

of the available mass. It should be noted however, that all of his runs were made at capacitor voltages of around 7KV, whereas the runs included in this paper were all made at 15KV.

No variation in mass deposition was observed with variation in pressure over the 10^{-4} mm. Hg. range for the runs with gold wire.

IV. SUGGESTIONS FOR FURTHER STUDY

Among the possibilities for further study are:

1. Measure the velocity of the plasma accelerating through the electrodes by means of oscilloscope monitored probes inserted through the walls of the outer electrode,

2. Determine the effect of capacitor voltage on the percent of gold recovered in a shot,

3. Devise a means of determining the diffusion coefficient of gold using the accelerator,

4. By varying the size, shape, or orientation of the center electrode, study the effects of an asymetrical magnetic field on the plasma flow,

5. Analyze the background activity from the aluminum foil collectors in order to determine its sources,

6. Conduct a detailed study of deposited plasma using microscopy.

TABLE 1

TRACER RESULTS FOR RUN 1 PRESSURE 1×10^{-4} mm. Hg.

IRRADIATED 19 MAY 69 - 1710 TOTAL MASS COLLECTED 57.52 μgm.

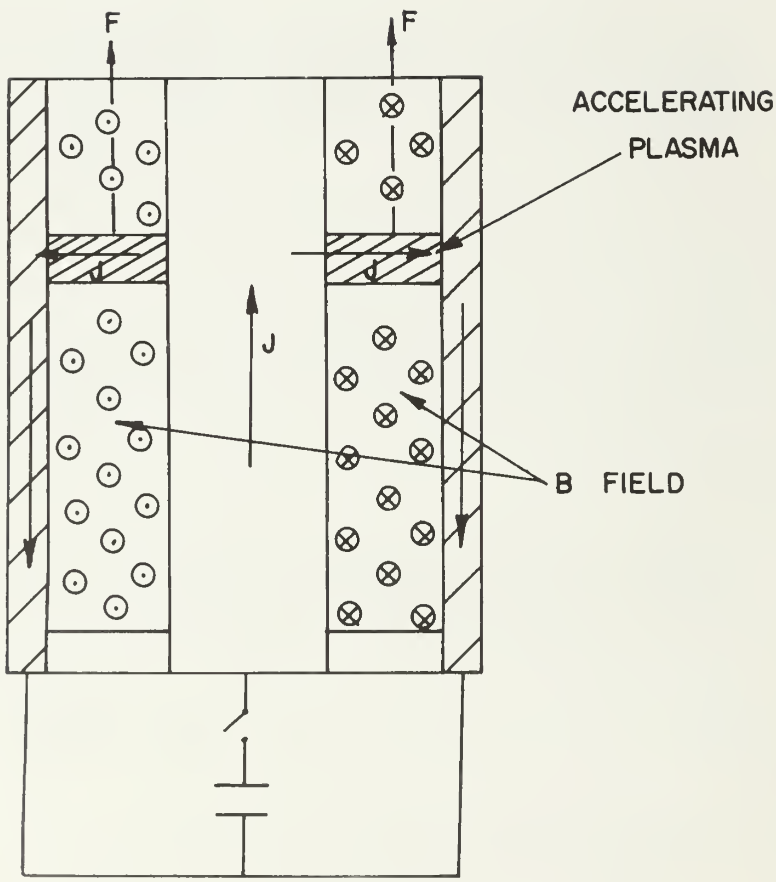
Sample Position Degrees	Sample Age Hours - Min.	Counting Time Min.	Activity Counts/Min.	Control Factor gm/Counts/Sec.	Collected Gold Concentration μgm./m^2
0	54 - 19	4	1,426	$.00906 \times 10^{-6}$	51.80
45	25	4	1,884	.00907	70.68
90	31	4	914	.00909	30.88
135	37	4	581	.00910	17.21
180	43	4	513	.00911	14.44
225	50	4	505	.00912	14.13
270	56	4	651	.00913	20.19
315	55 - 03	4	1,185	.00914	42.29

TABLE 2

TRACER RESULTS FOR RUN 13 PRESSURE 5×10^{-4} mm. Hg.

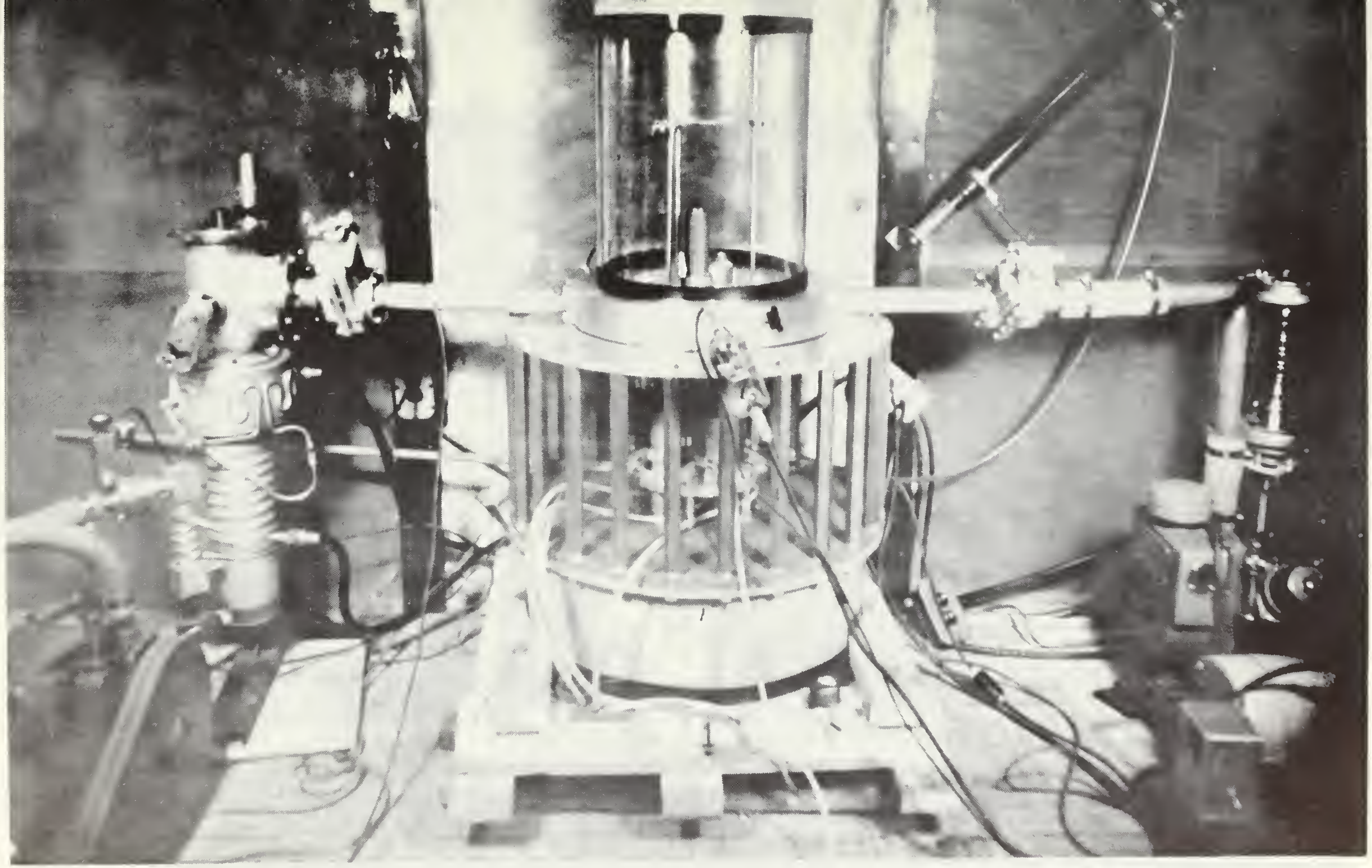
IRRADIATED 28 MAY 69 1535 TOTAL MASS COLLECTED 14,985 gm.

Sample Position Circle-Deg.	Age Hrs. - Min.	Counting Time - Min.	Activity Counts/Min.	Control Factor gm./Counts/Sec.	Collected Gold Conc. μgm./in^2
0 - 0	44 - 57	1	8302	$.00937 \times 10^{-6}$	185.9
1 - 0	45 - 01	1	96102	.00938	2221.5
1 - 90	- 03	1	110967	.00938	2487.8
1 - 180	- 06	1	348645	.00939	7824.4
1 - 270	- 10	1	207710	.00940	4666.2
2 - 0	- 15	2	932	.00941	21.0
2 - 45	- 22	2	939	.00942	21.2
2 - 90	- 24	2	717	.00943	16.0
2 - 135	- 28	2	611	.00943	13.8
2 - 180	- 30	2	316	.00944	7.1
2 - 225	- 36	2	353	.00944	8.0
2 - 270	- 40	2	372	.00945	8.4
2 - 315	- 44	2	602	.00946	13.6
3 - 0	- 57	4	93	.00947	2.1
3 - 45	46 - 03	4	100	.00948	2.3
3 - 90	10	4	54	.00949	1.2
3 - 135	15	4	46	.00949	1.0
3 - 180	21	4	27	.00950	.6
3 - 225	27	4	37	.00951	.8
3 - 270	32	4	82	.00952	1.9
3 - 315	37	4	41	.00953	.9
4 - 0	42	4	14	.00954	.3
4 - 45	50	4	25	.00956	.6
4 - 90	55	4	27	.00957	.6
4 - 135	47 - 01	4	45	.00958	1.0
4 - 180	11	4	4	.00959	.1
4 - 225	16	4	13	.00960	.3
4 - 270	18	4	29	.00961	.7
4 - 315	23	4	34	.00962	.8



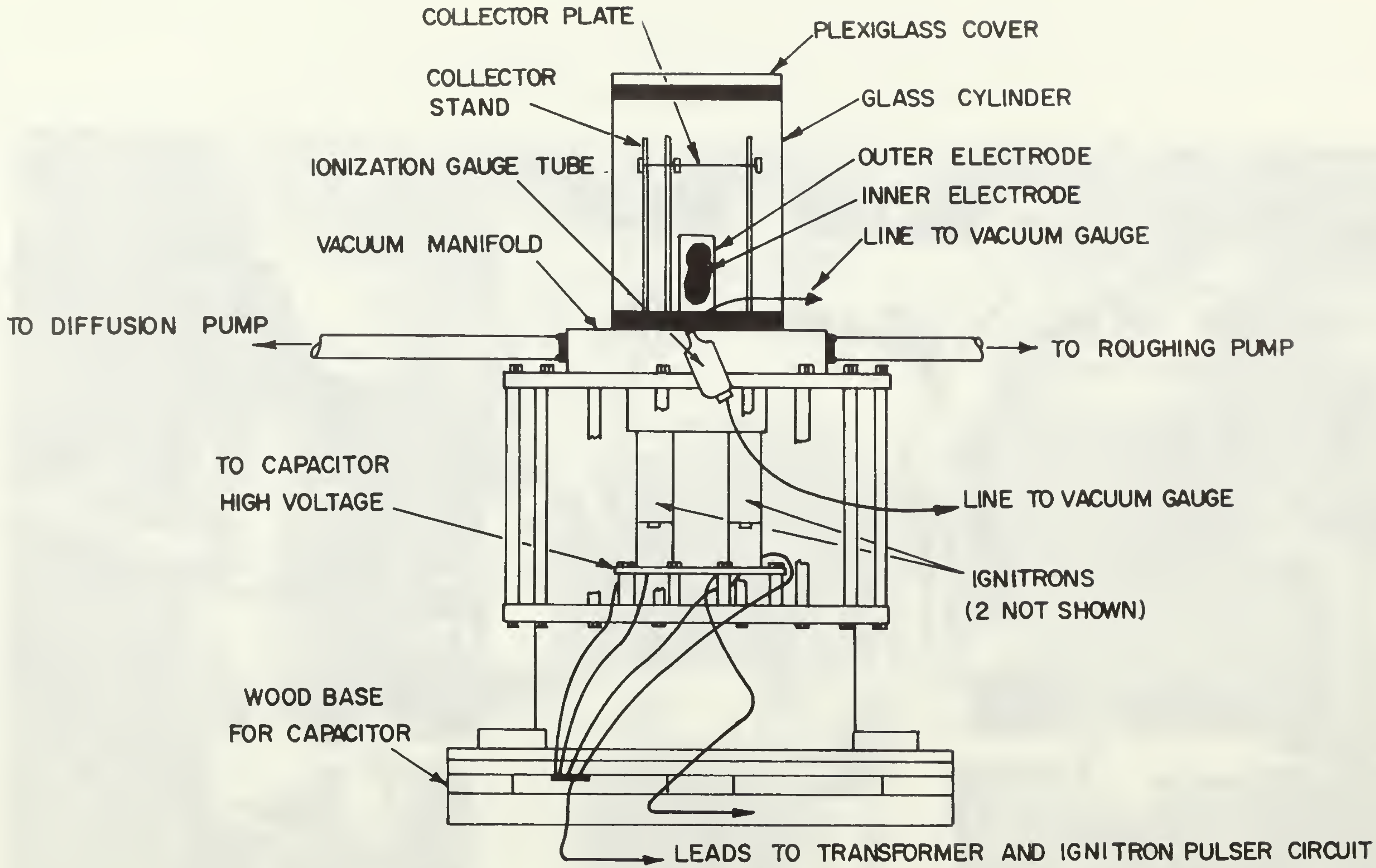
SCHEMATIC OF COAXIAL PLASMA ACCELERATOR

FIGURE 1



PLASMA ACCELERATOR AND VACUUM SYSTEMS

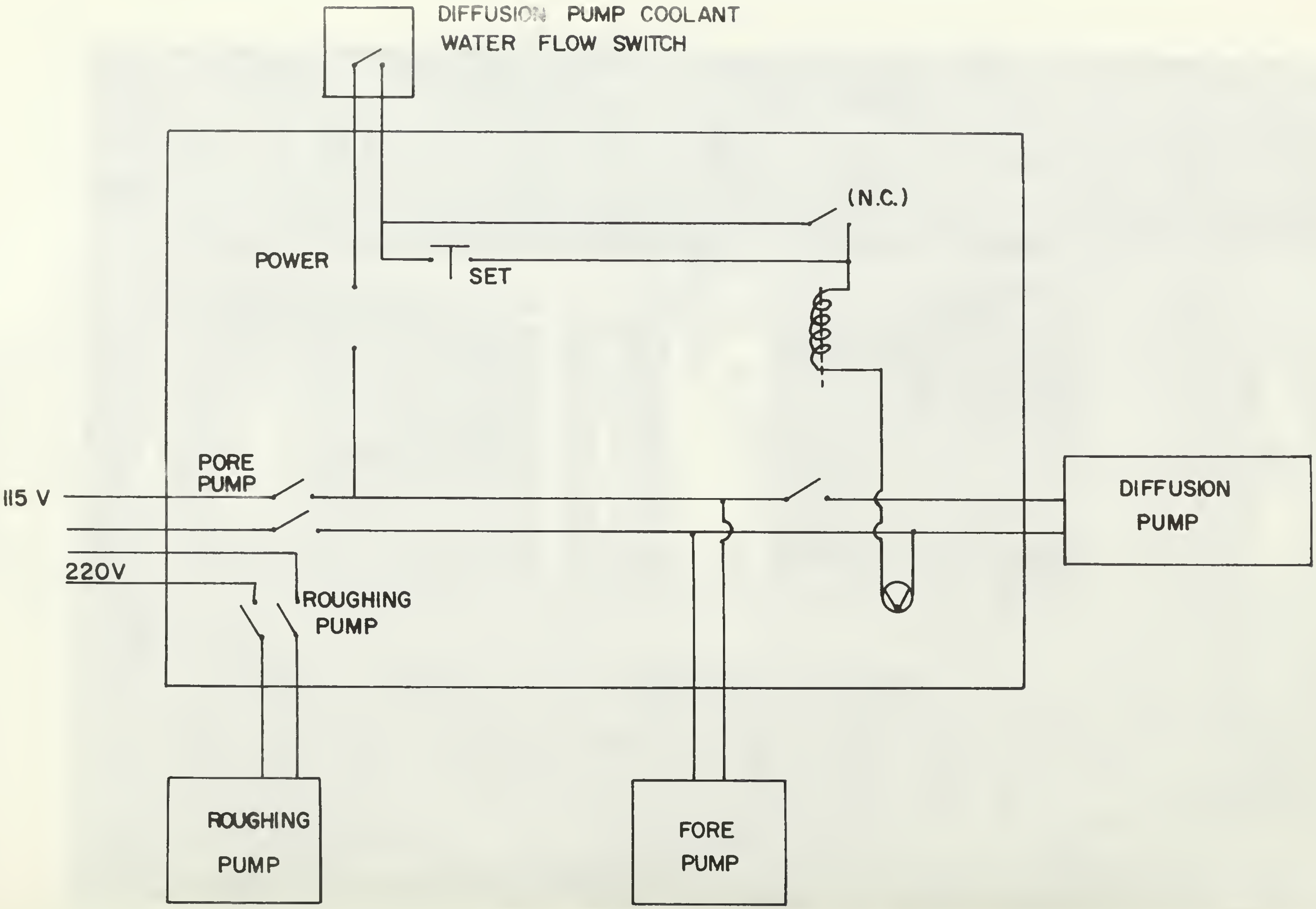
FIGURE 2



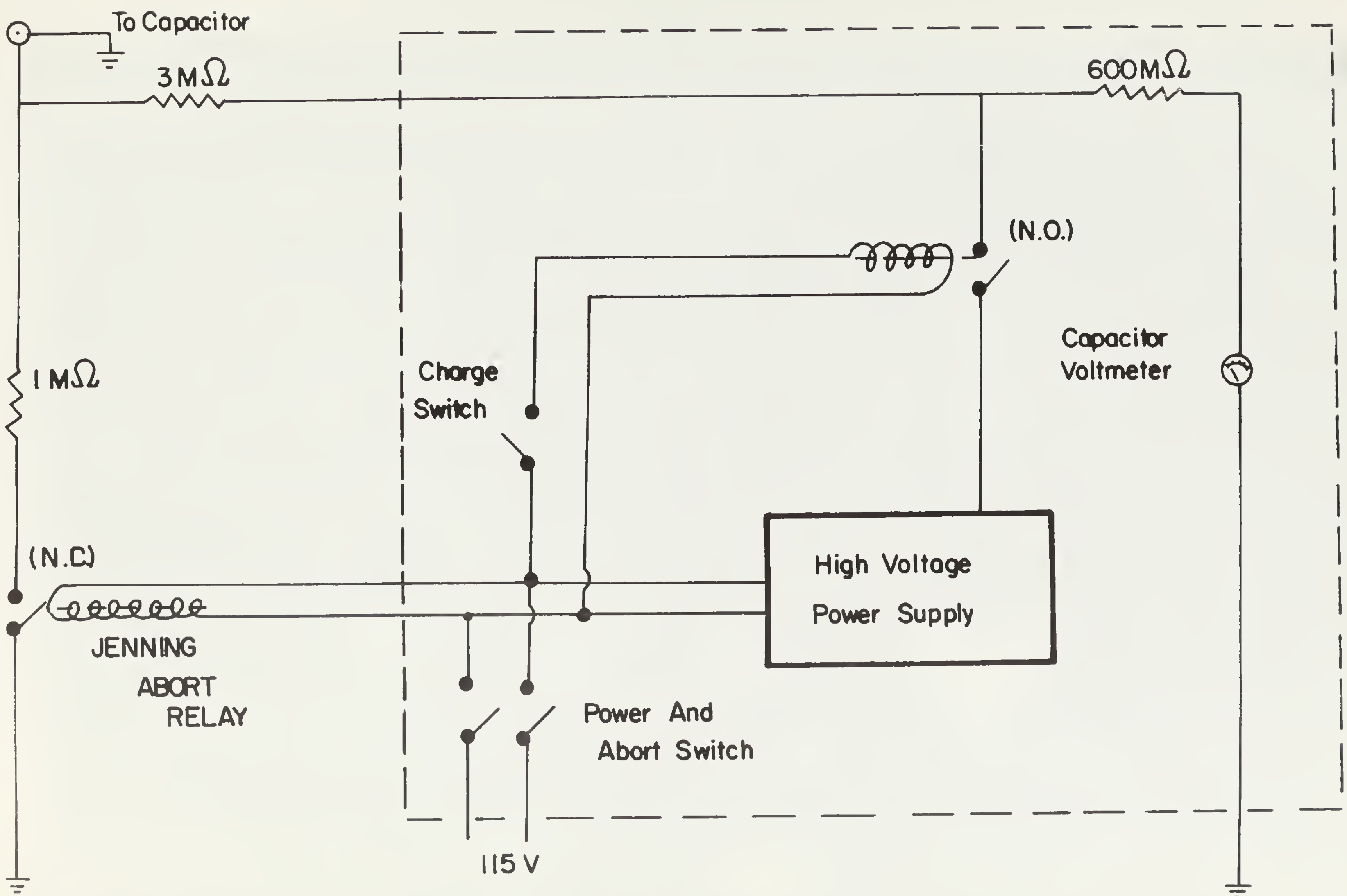
CAPACITOR, IGNITRONS, AND VACUUM SYSTEM

FIGURE 3

VACUUM CONTROL PANEL
PULSING POWER SUPPLY
AND TRANSFORMER
FIGURE 4



VACUUM CONTROLS
FIGURE 5

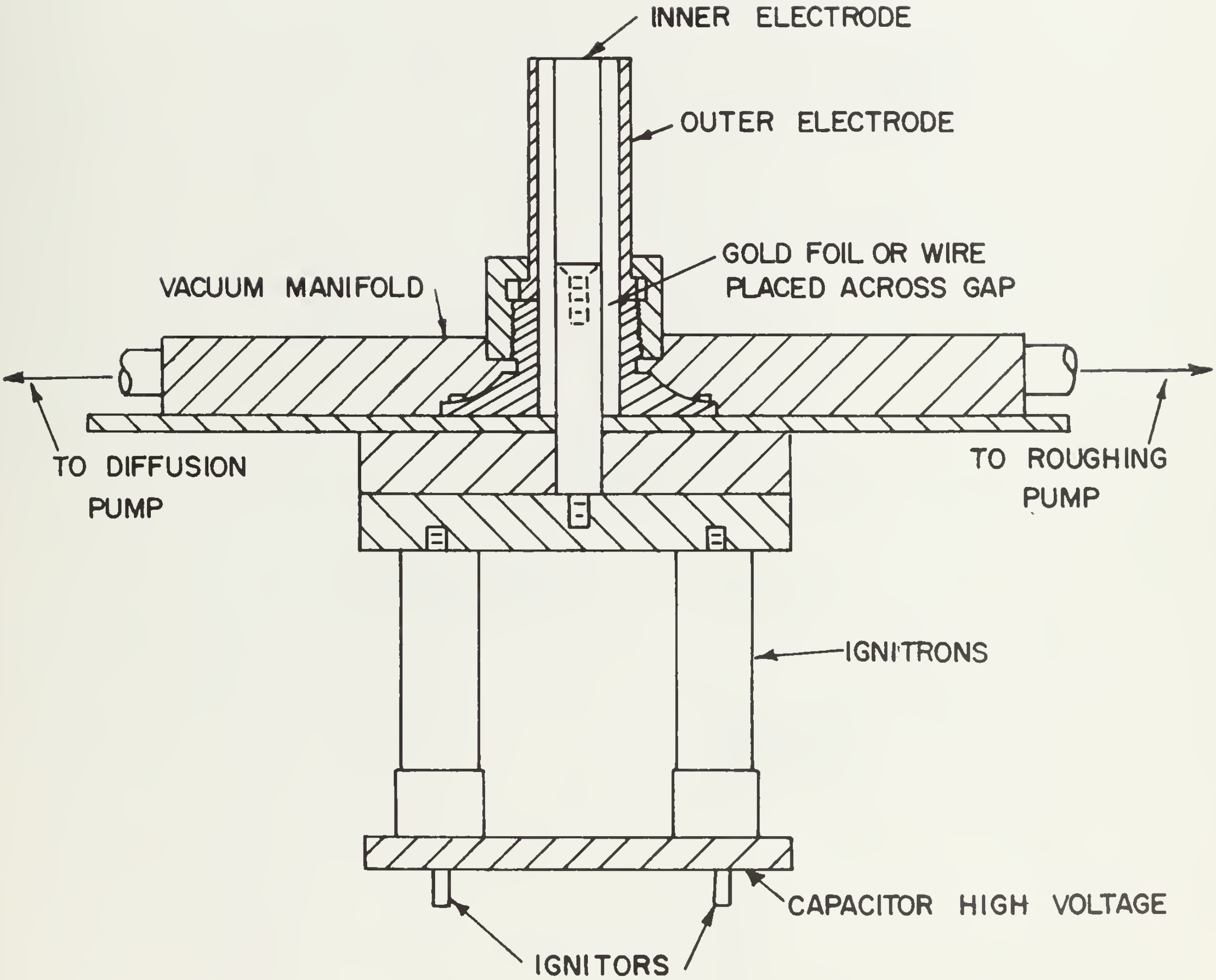


HIGH VOLTAGE SYSTEM

FIGURE 6

HIGH VOLTAGE POWER SUPPLY
CONTROL PANEL

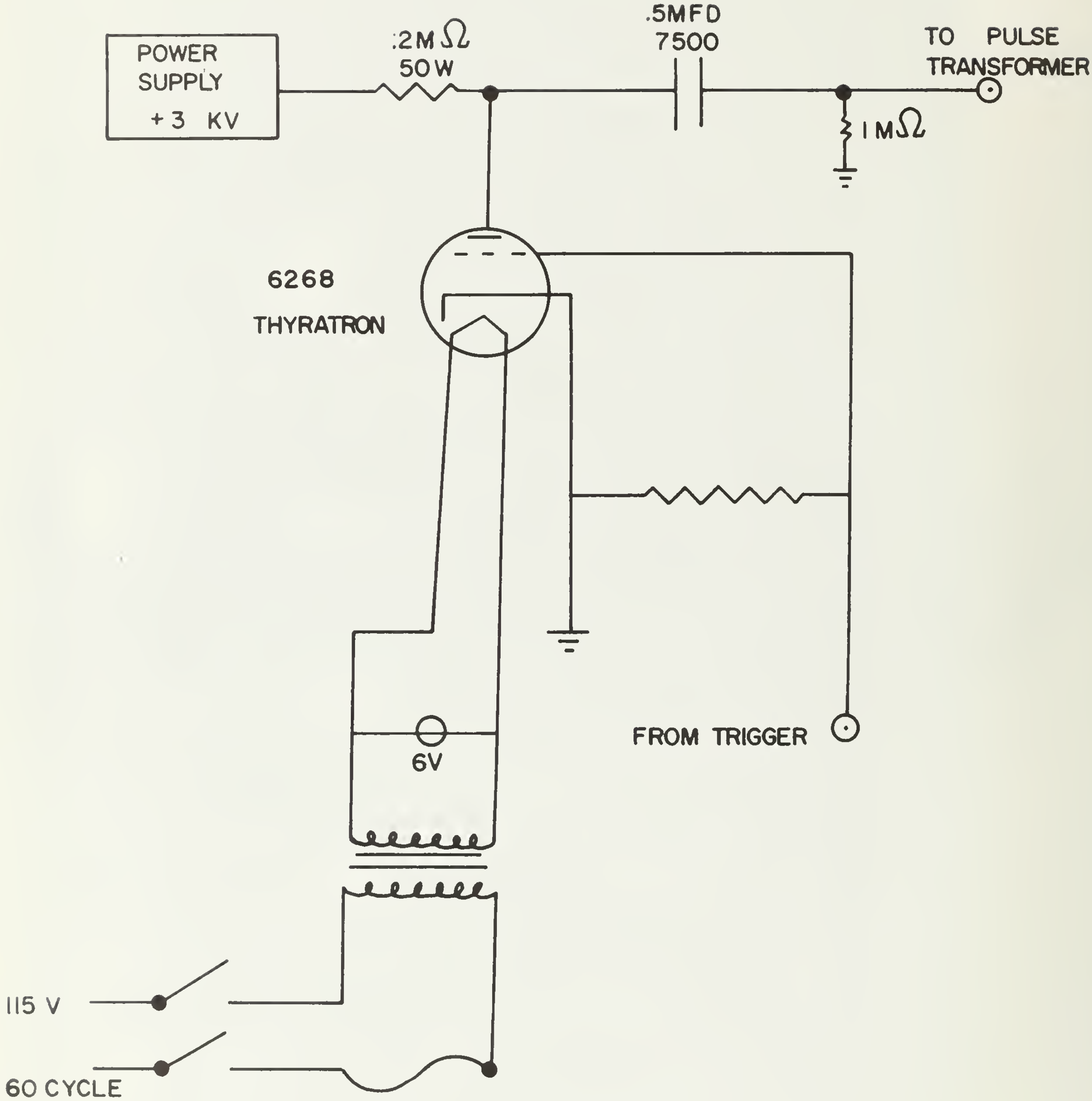
FIGURE 7



ELECTRODE AND IGNITRON

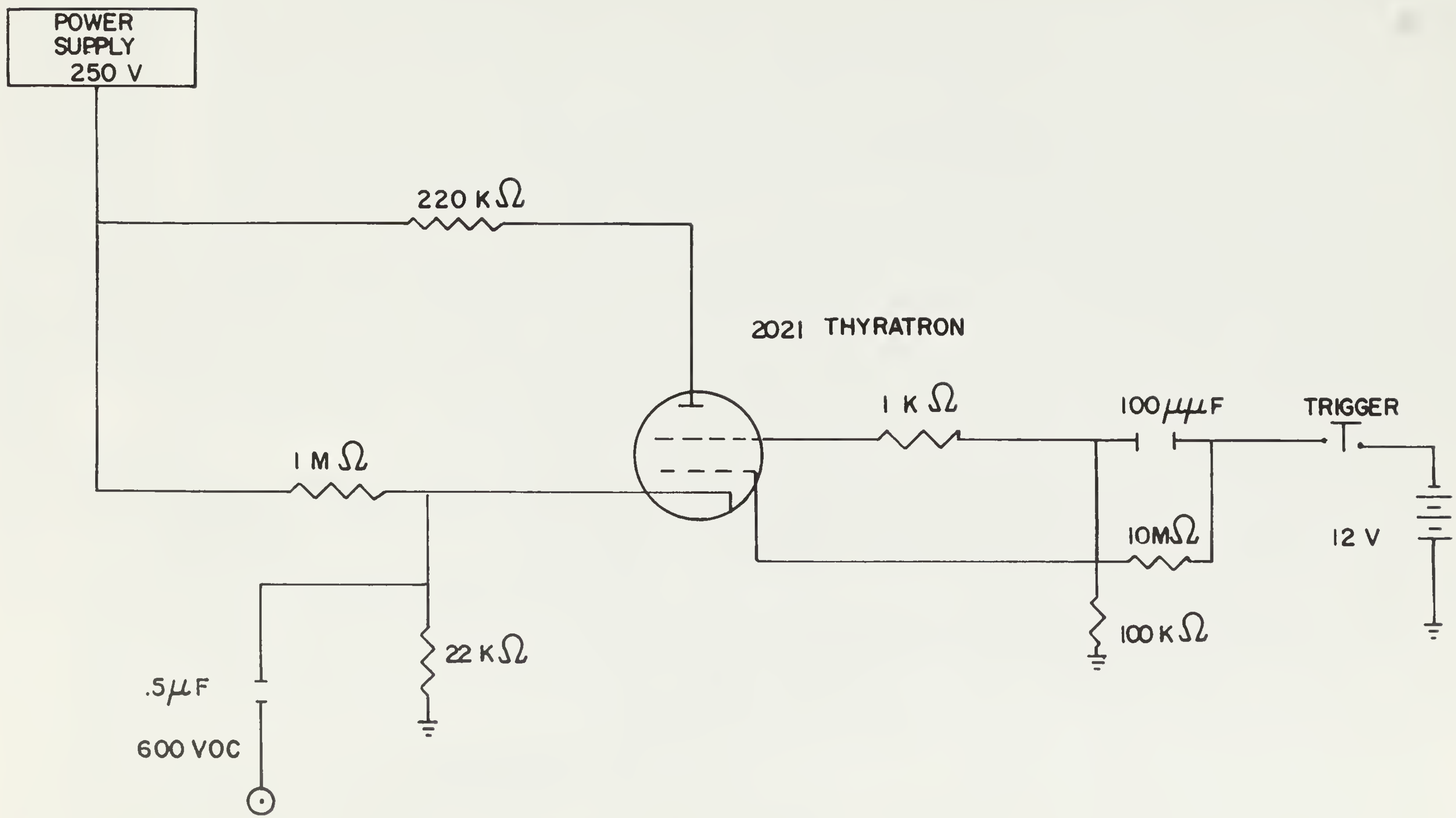
ARRANGEMENT

FIGURE 8



IGNITRON PULSER

FIGURE 9

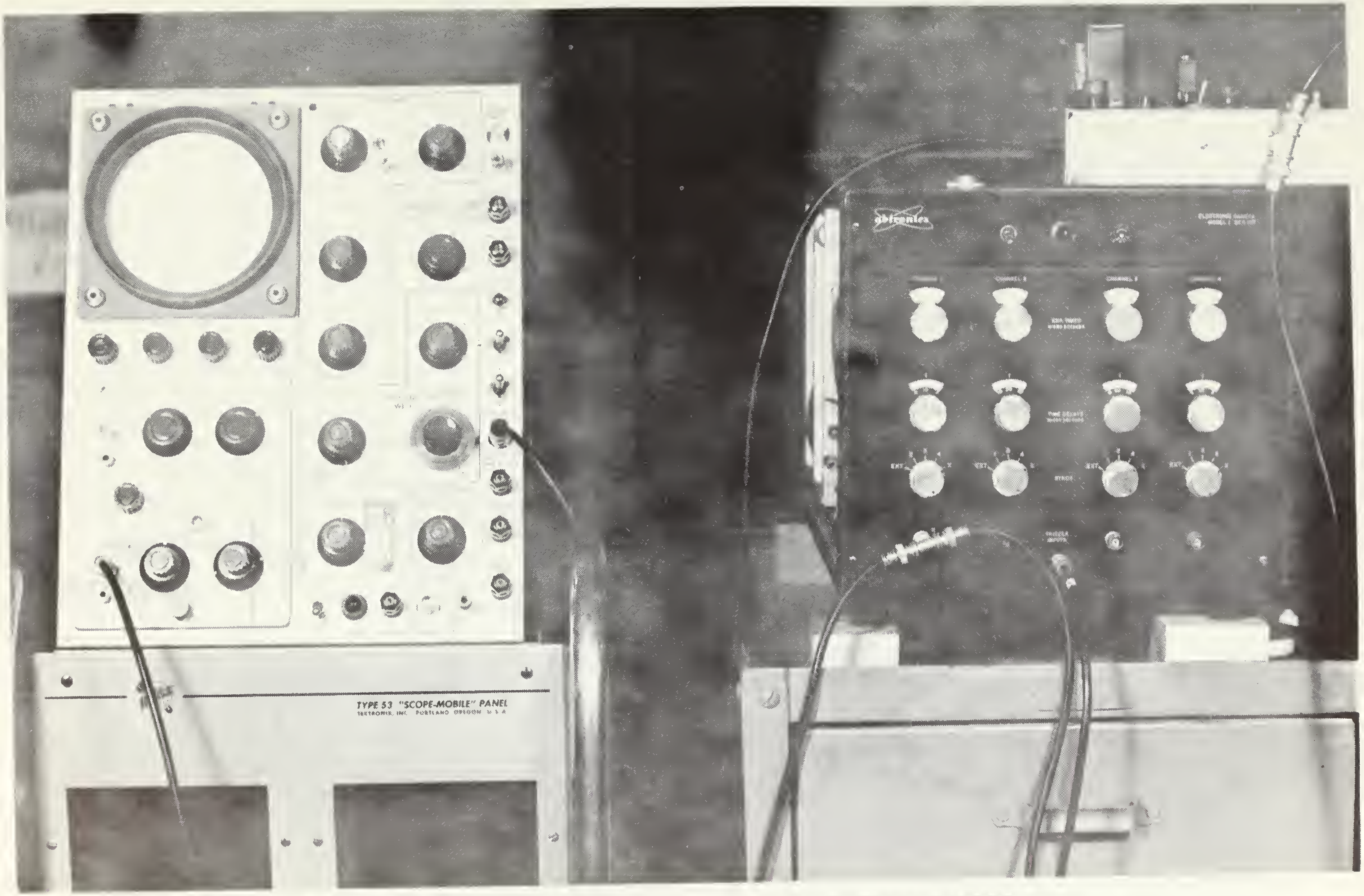


CAPACITOR DISCHARGE TRIGGER

FIGURE 10

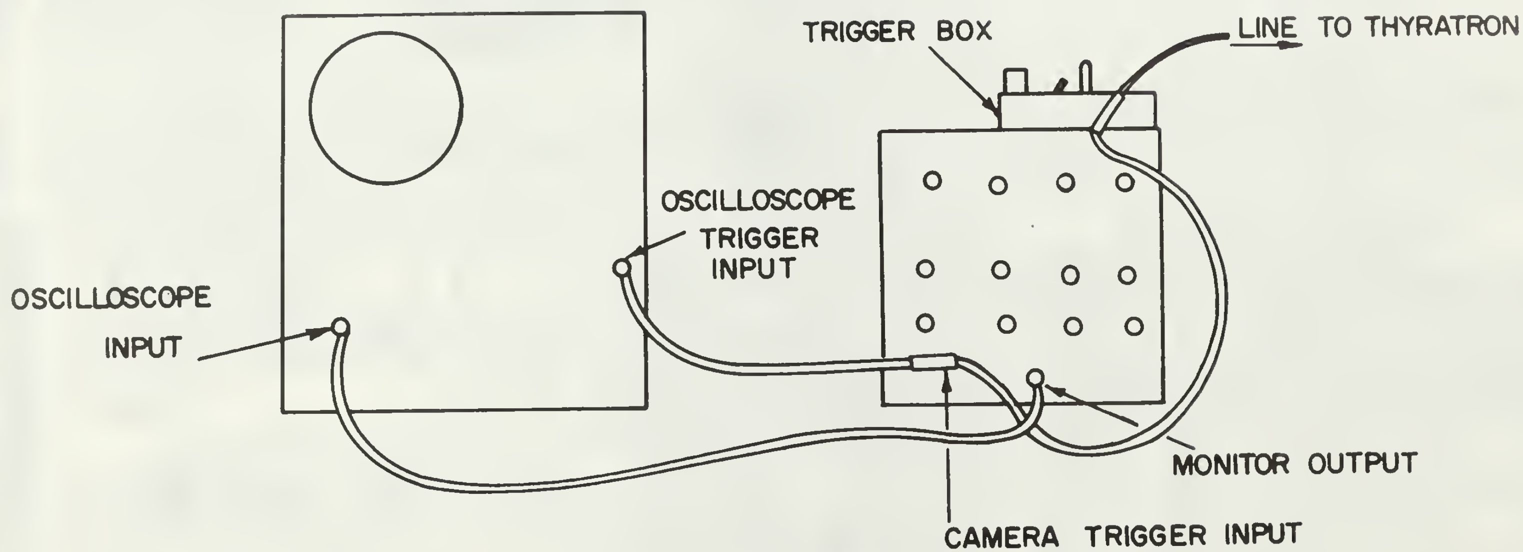
IMAGE CONVERTER CAMERA

FIGURE 11



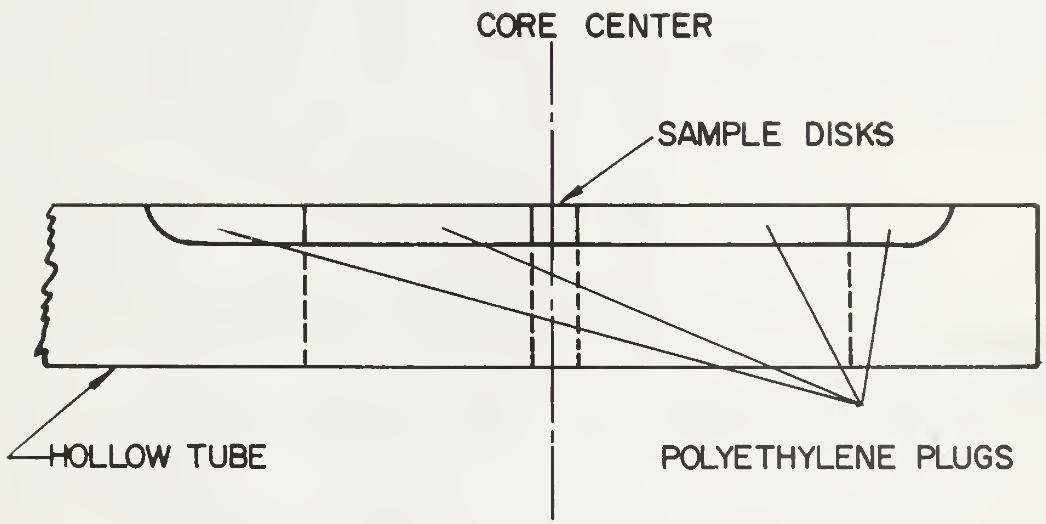
TRIGGER BOX — CAMERA CONTROLS AND OSCILLOSCOPE

FIGURE 12



TRIGGERING CONNECTIONS FOR CAMERA AND OSCILLOSCOPE

FIGURE 13

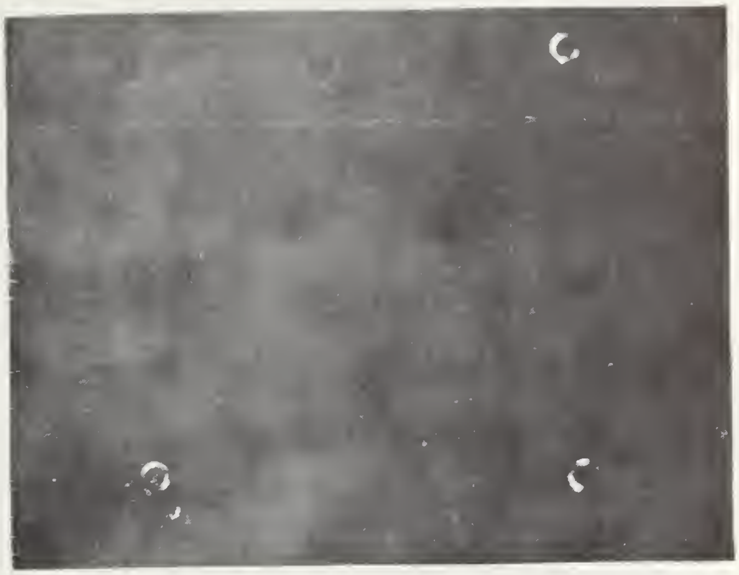


SAMPLE DISKS ARRANGED
FOR IRRADIATION

FIGURE 14

SAMPLE PREPARATION EQUIPMENT

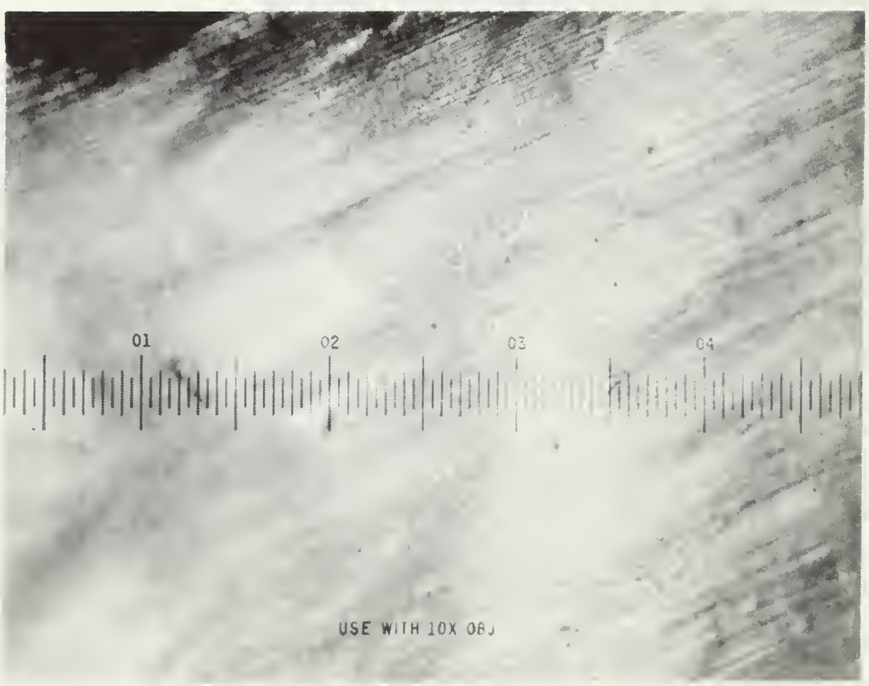
FIGURE 15



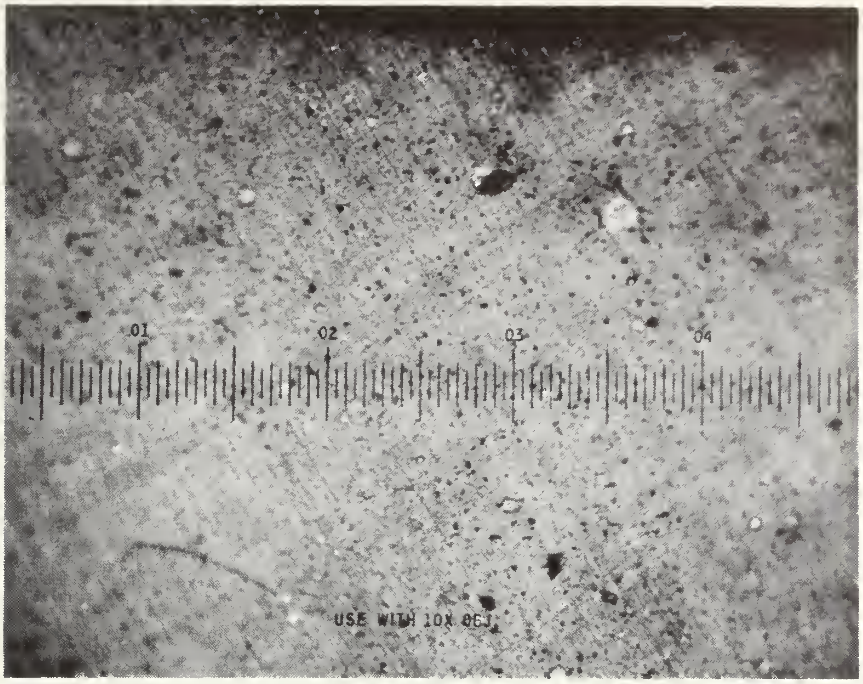
PLASMA FROM .005 in.
DIAMETER GOLD WIRE
FIGURE 16

PLASMA FROM .00005 in.
THICK GOLD FOIL
FIGURE 17

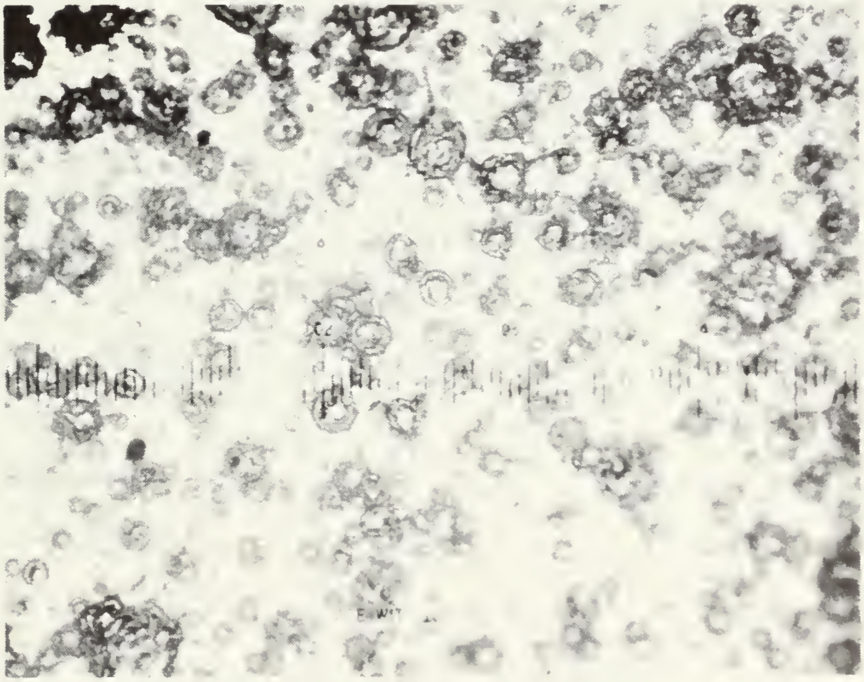
PLAIN ALUMINUM FOIL COLLECTOR
FIGURE 18



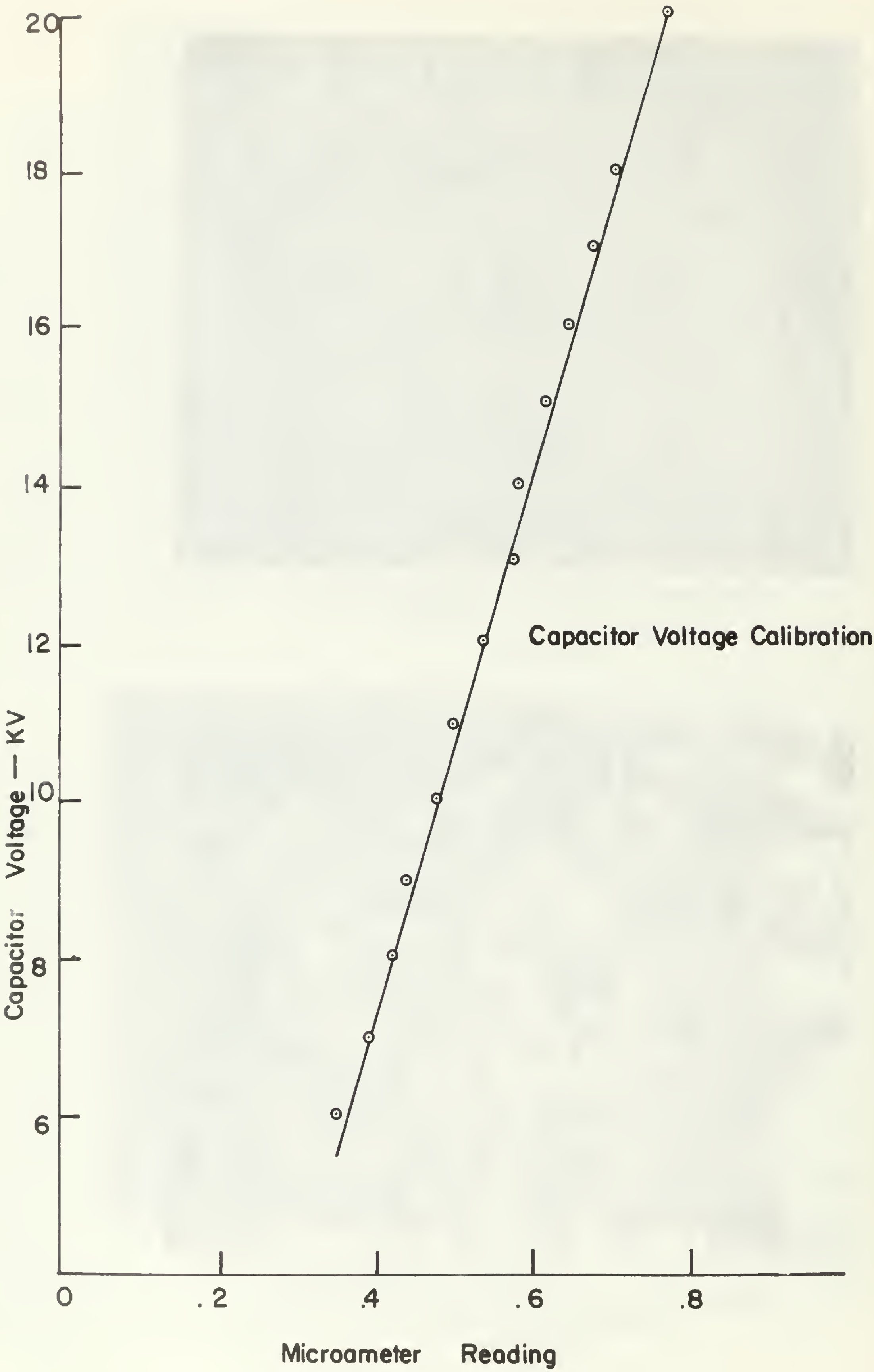
DEPOSITED PLASMA FROM .005 in.
DIAMETER GOLD WIRE
FIGURE 19



DEPOSITED PLASMA FROM .020 in.
DIAMETER GOLD WIRE
FIGURE 20



DEPOSITED PLASMA FROM .00005 in.
THICK GOLD FOIL
FIGURE 21


Capacitor Voltage Calibration
Capacitor Voltage — KV
20
18
16
14
12
10
8
6
0
.2
.4
.6
.8
Microameter Reading
FIGURE 22

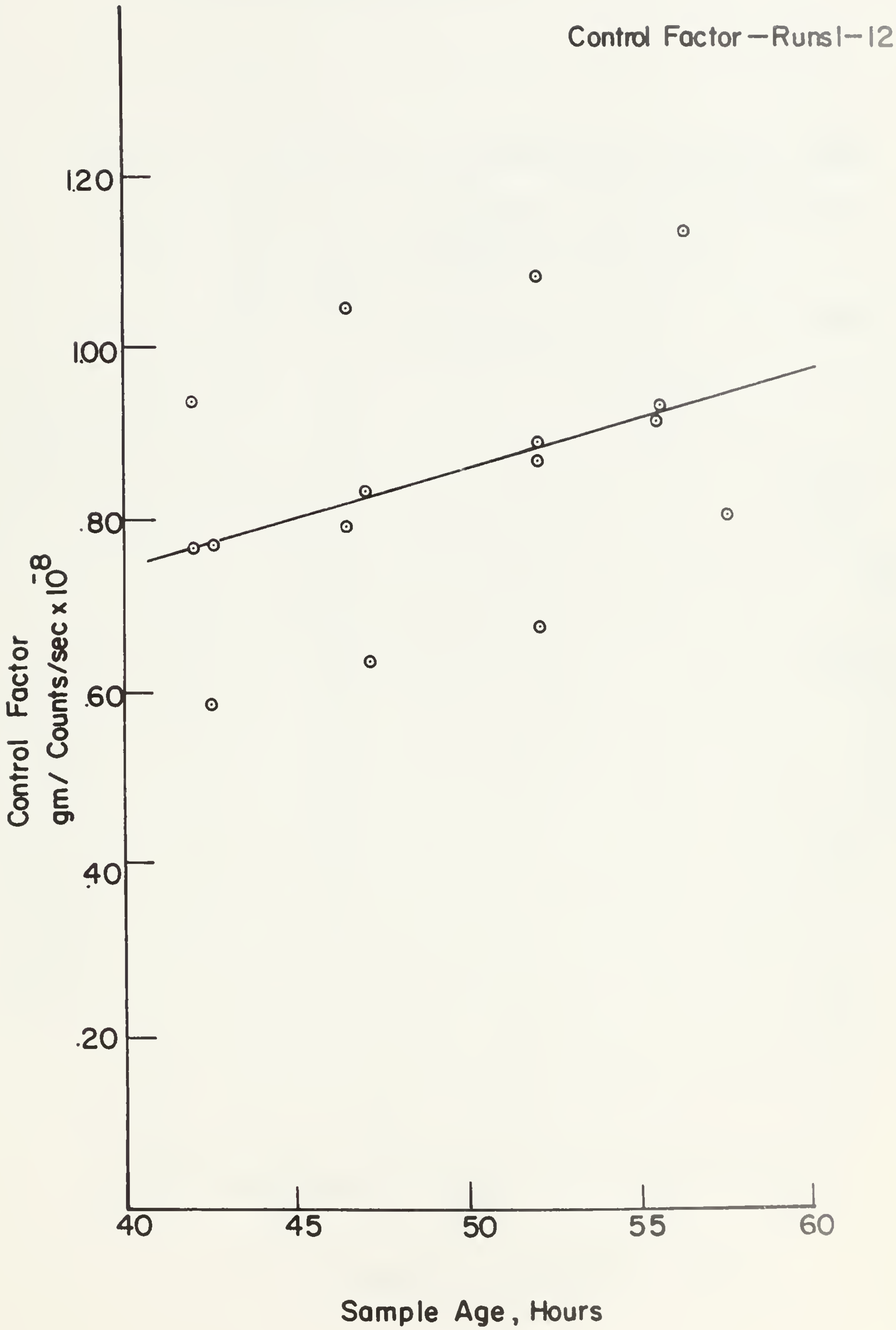

Control Factor—Runs 1–12
1.20
1.00
.80
.60
.40
.20
Control Factor
gm/ Counts/sec x 10^-8
40
45
50
55
60
Sample Age, Hours

FIGURE 23

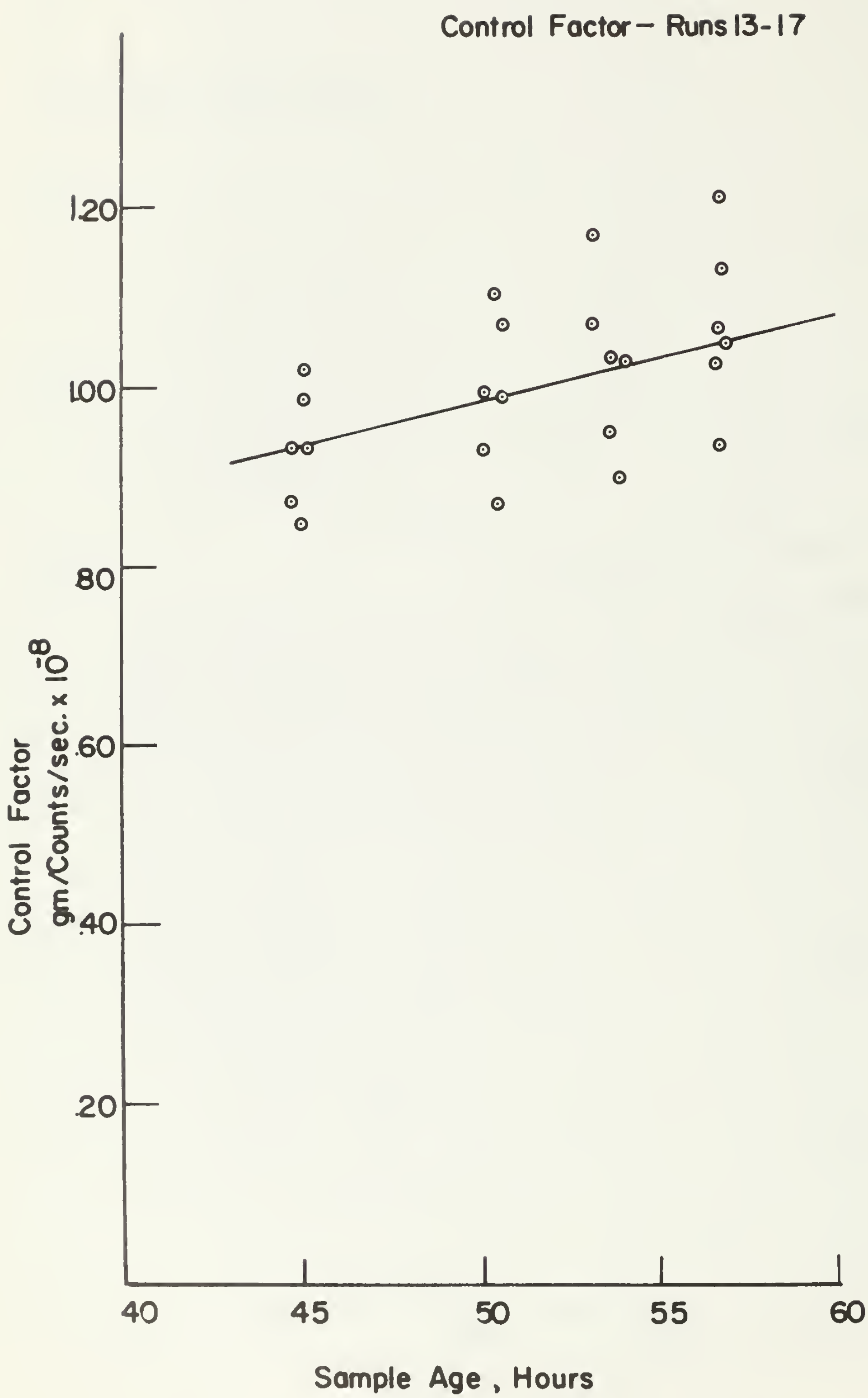

Control Factor – Runs 13-17
Control Factor
gm/Counts/sec. x 10^{-8}
1.20
1.00
.80
.60
.40
.20
40
45
50
55
60
Sample Age , Hours

FIGURE 24

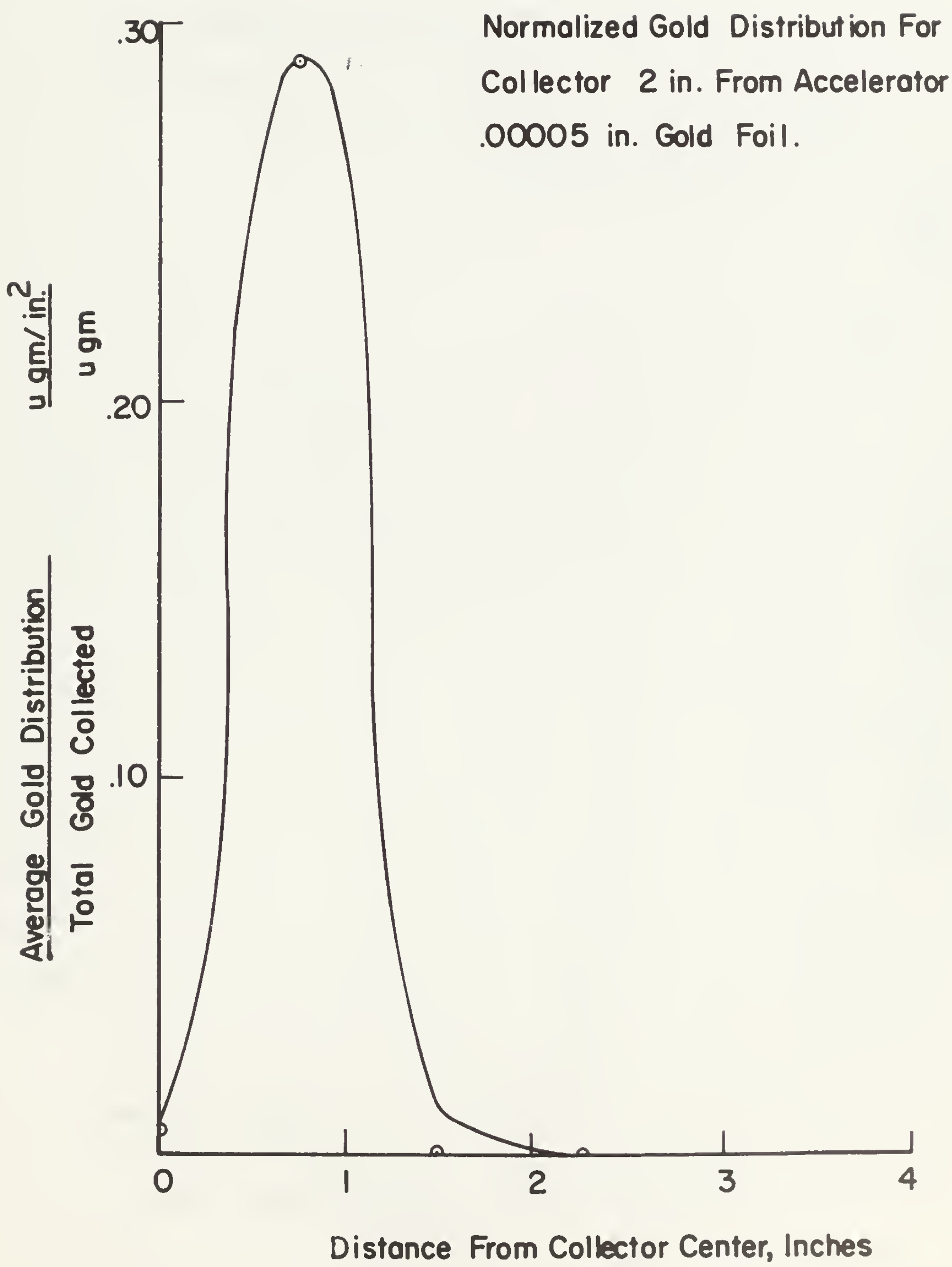
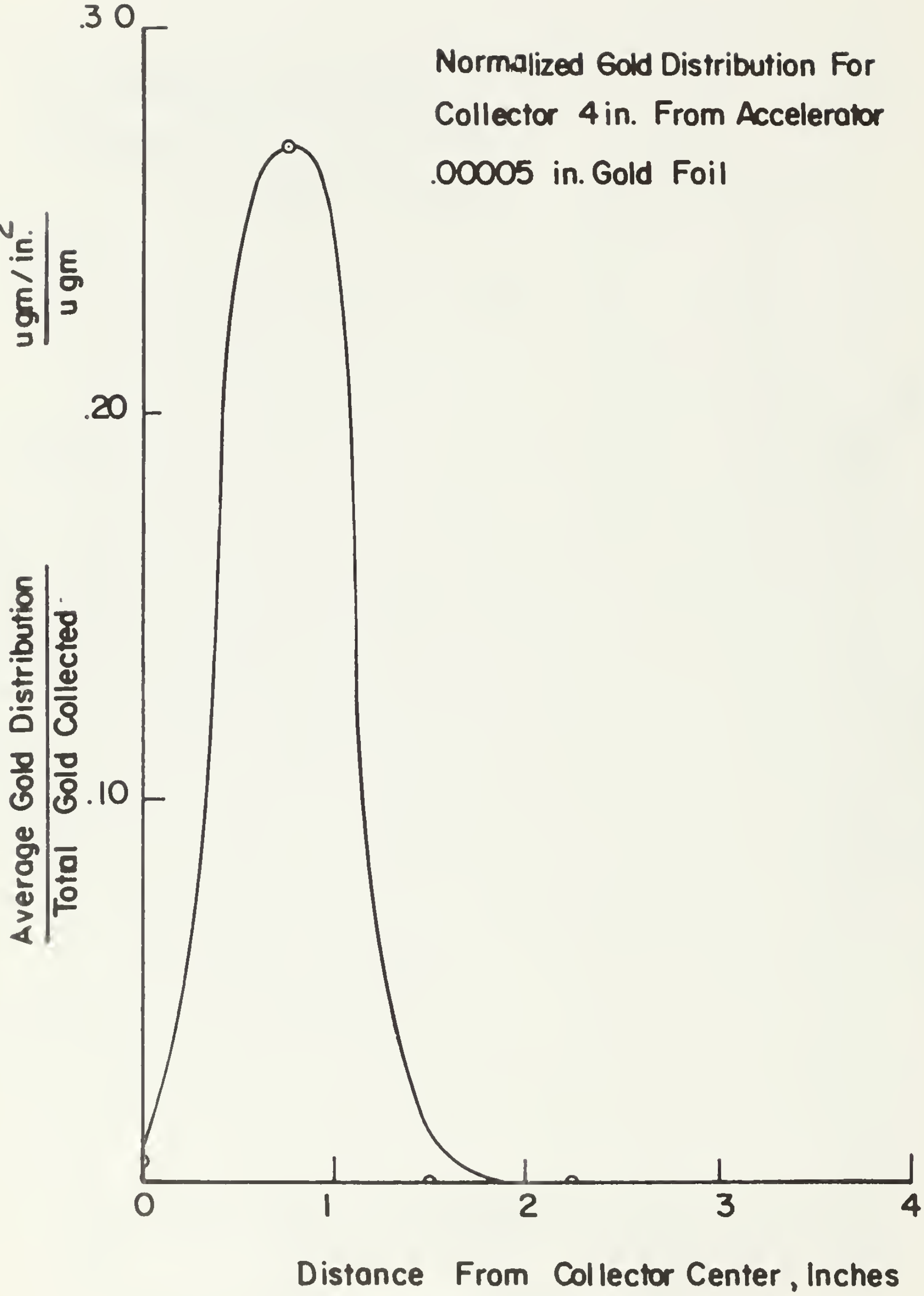
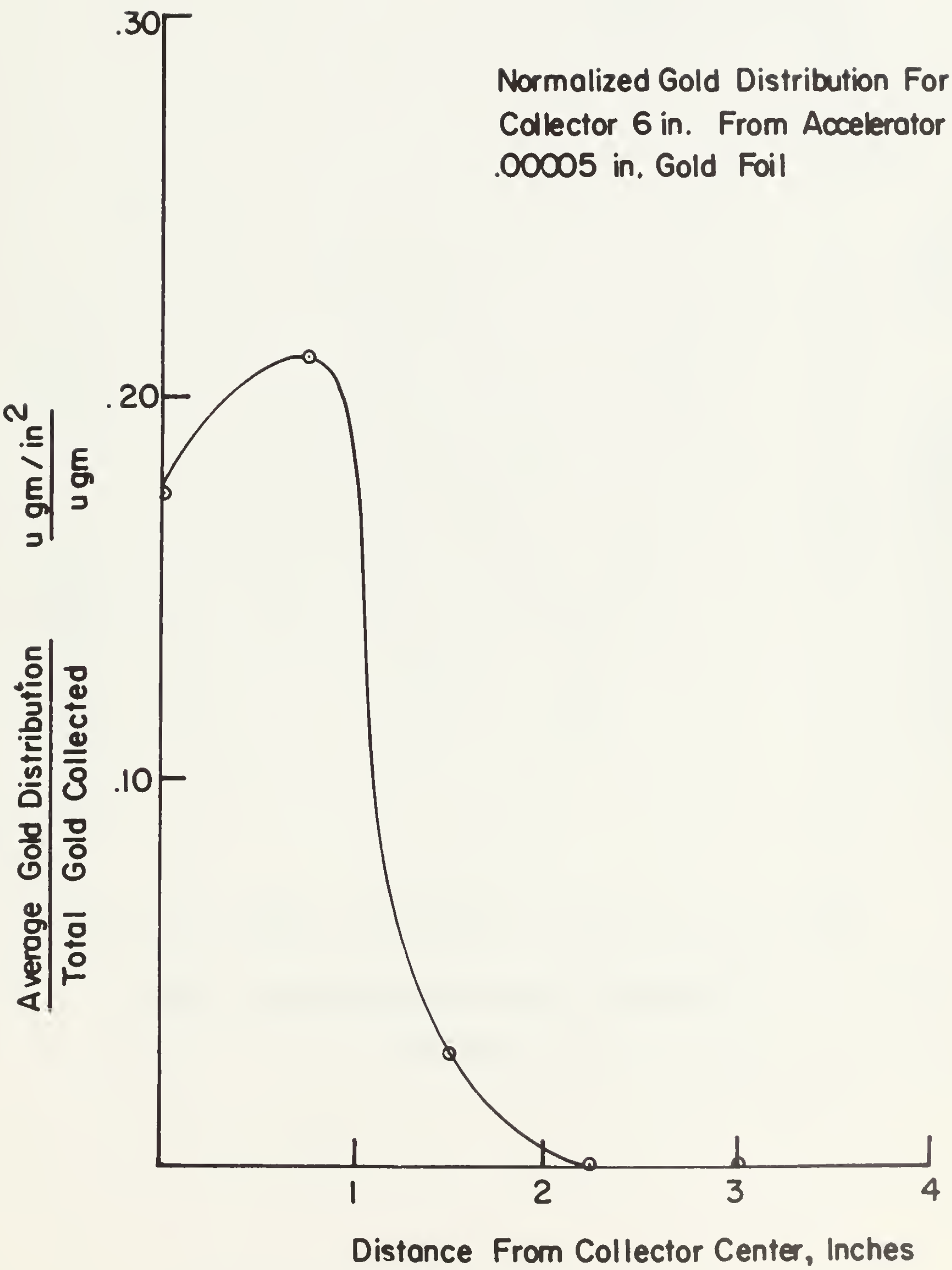

Normalized Gold Distribution For
Collector 2 in. From Accelerator
.00005 in. Gold Foil.
.30
.20
.10
Average Gold Distribution / Total Gold Collected
u gm/in.2 / u gm
0
1
2
3
4
Distance From Collector Center, Inches

FIGURE 25



Normalized Gold Distribution For
Collector 4 in. From Accelerator
.00005 in. Gold Foil
Average Gold Distribution / Total Gold Collected
ugm/in.^2 / ugm
.30
.20
.10
0
1
2
3
4
Distance From Collector Center, Inches

FIGURE 26



Normalized Gold Distribution For
Collector 6 in. From Accelerator
.00005 in. Gold Foil
.30
.20
.10
1
2
3
4
Average Gold Distribution / Total Gold Collected
u gm/in^2 / u gm
Distance From Collector Center, Inches

FIGURE 27

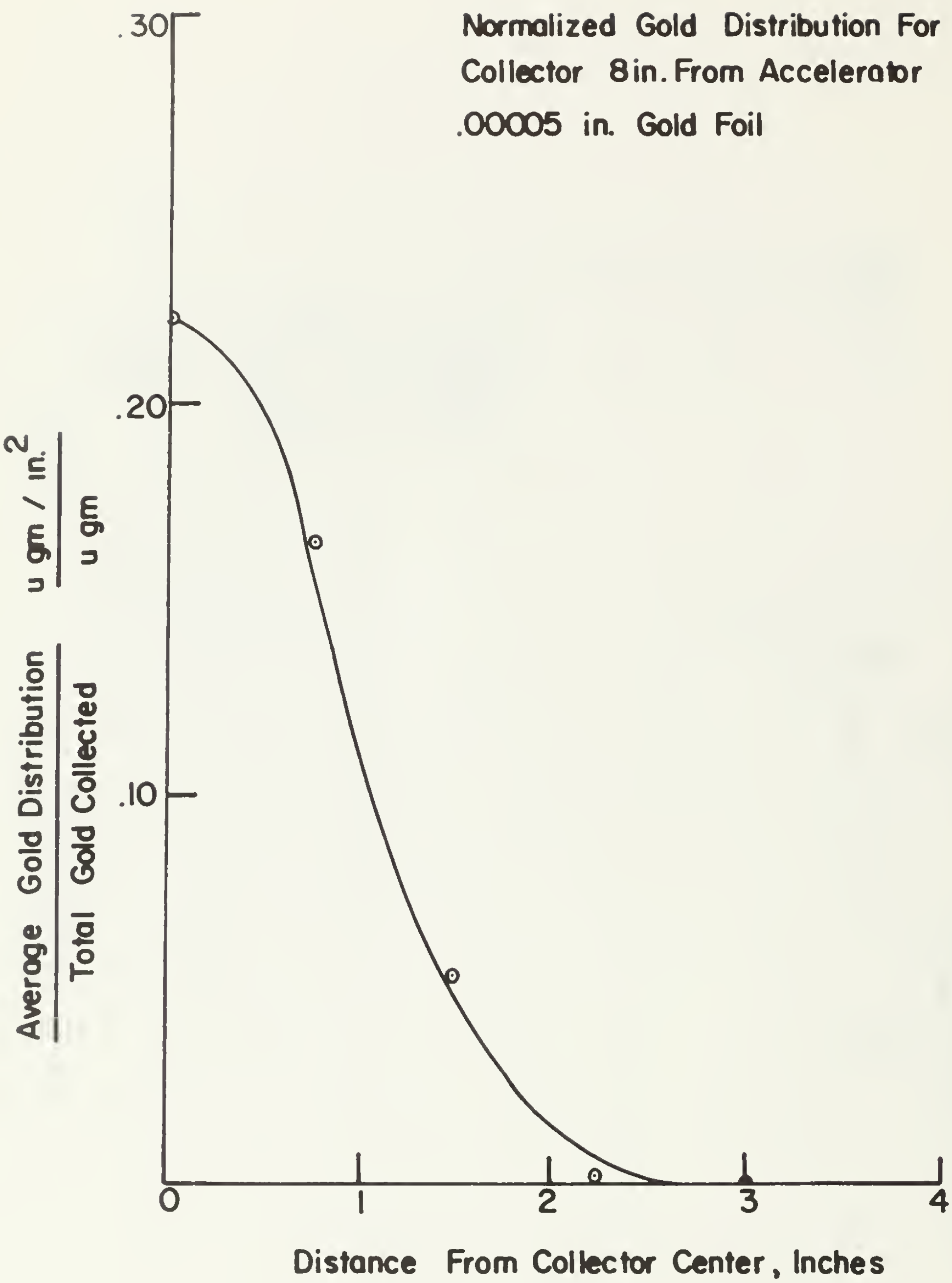

Normalized Gold Distribution For
Collector 8in. From Accelerator
.00005 in. Gold Foil
.30
.20
.10
Average Gold Distribution / Total Gold Collected
u gm / in.^{2} / u gm
0
1
2
3
4
Distance From Collector Center, Inches

FIGURE 28

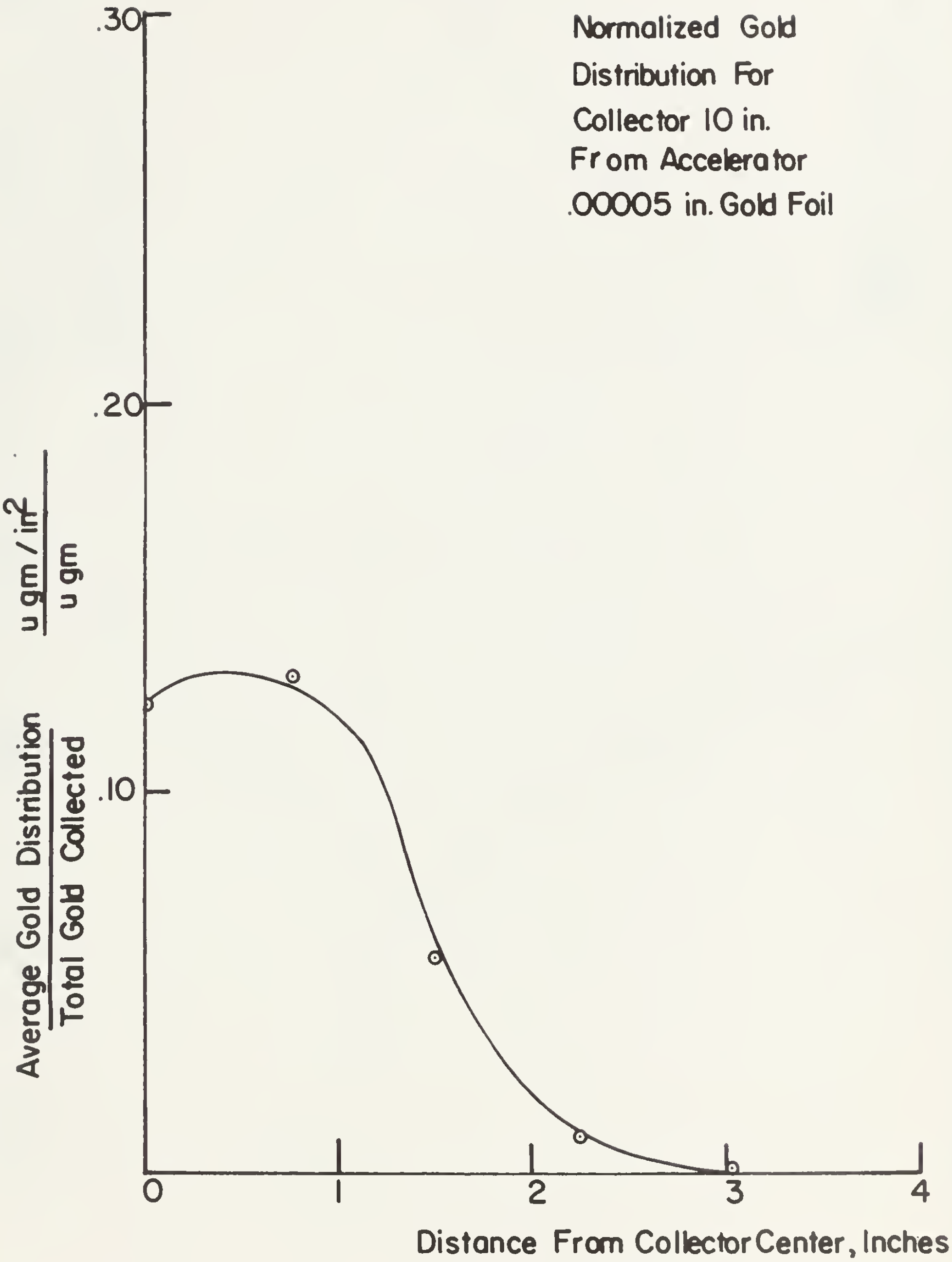
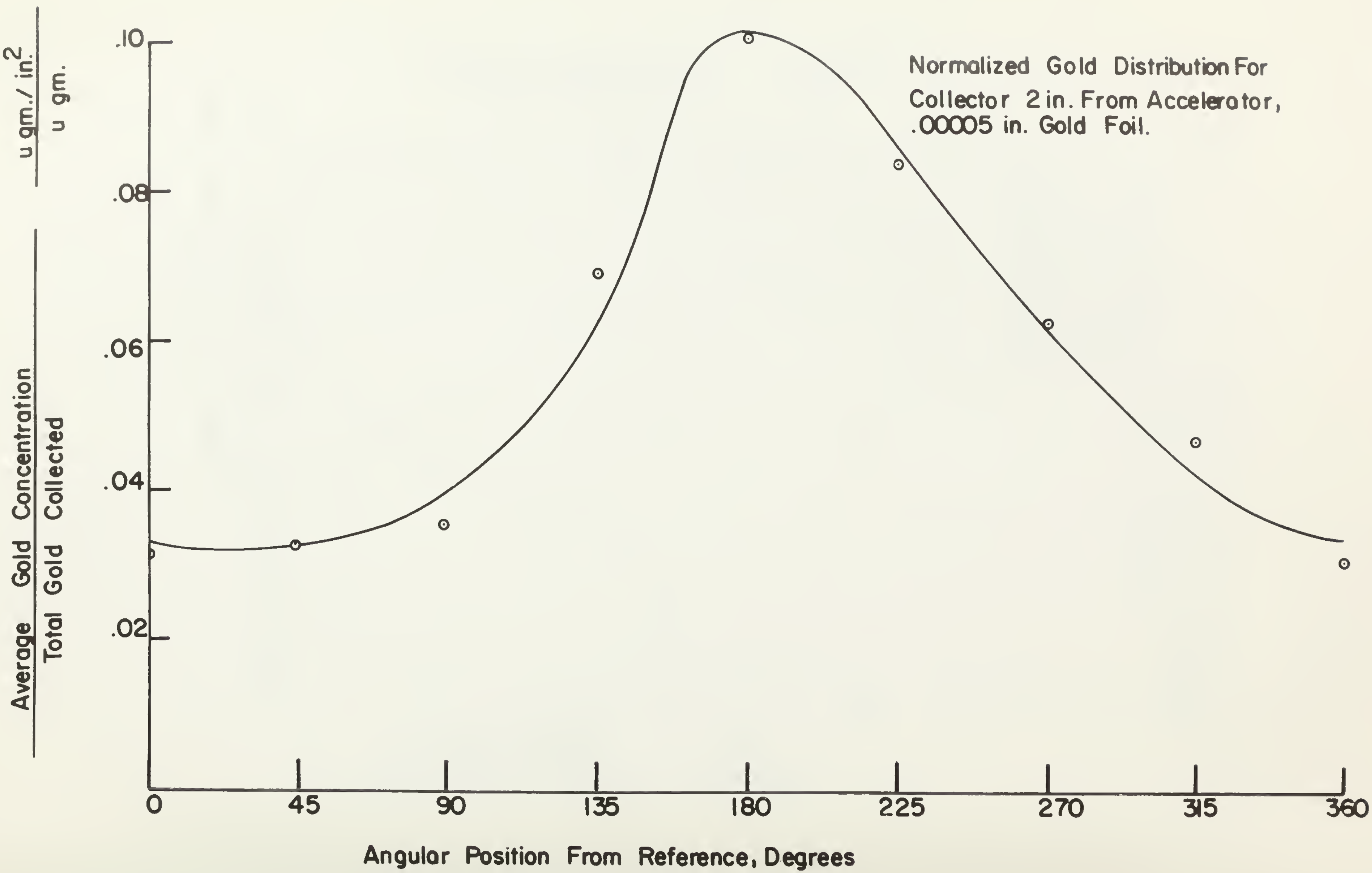

Normalized Gold
Distribution For
Collector 10 in.
From Accelerator
.00005 in. Gold Foil
.30
.20
.10
Average Gold Distribution / Total Gold Collected   u gm / in² / u gm
0
1
2
3
4
Distance From Collector Center, Inches

FIGURE 29


Average Gold Concentration
Total Gold Collected
u gm./ in.2
u gm.
.10
.08
.06
.04
.02
0
45
90
135
180
225
270
315
360
Normalized Gold Distribution For
Collector 2 in. From Accelerator,
.00005 in. Gold Foil.
Angular Position From Reference, Degrees
FIGURE 30

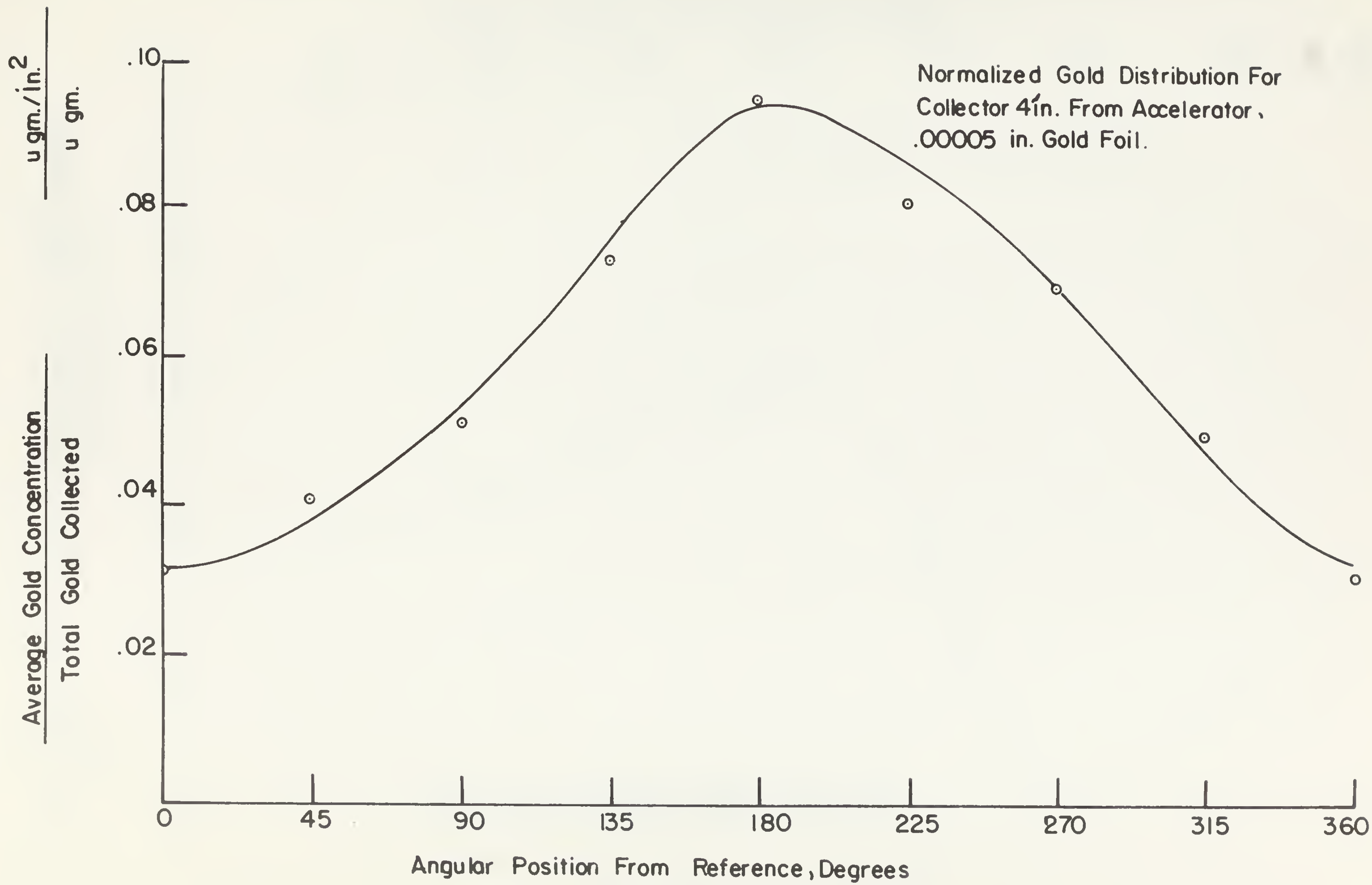

Normalized Gold Distribution For
Collector 4in. From Accelerator,
.00005 in. Gold Foil.
u gm./in.2
u gm.
Average Gold Concentration
Total Gold Collected
.10
.08
.06
.04
.02
0
45
90
135
180
225
270
315
360
Angular Position From Reference, Degrees

FIGURE 31

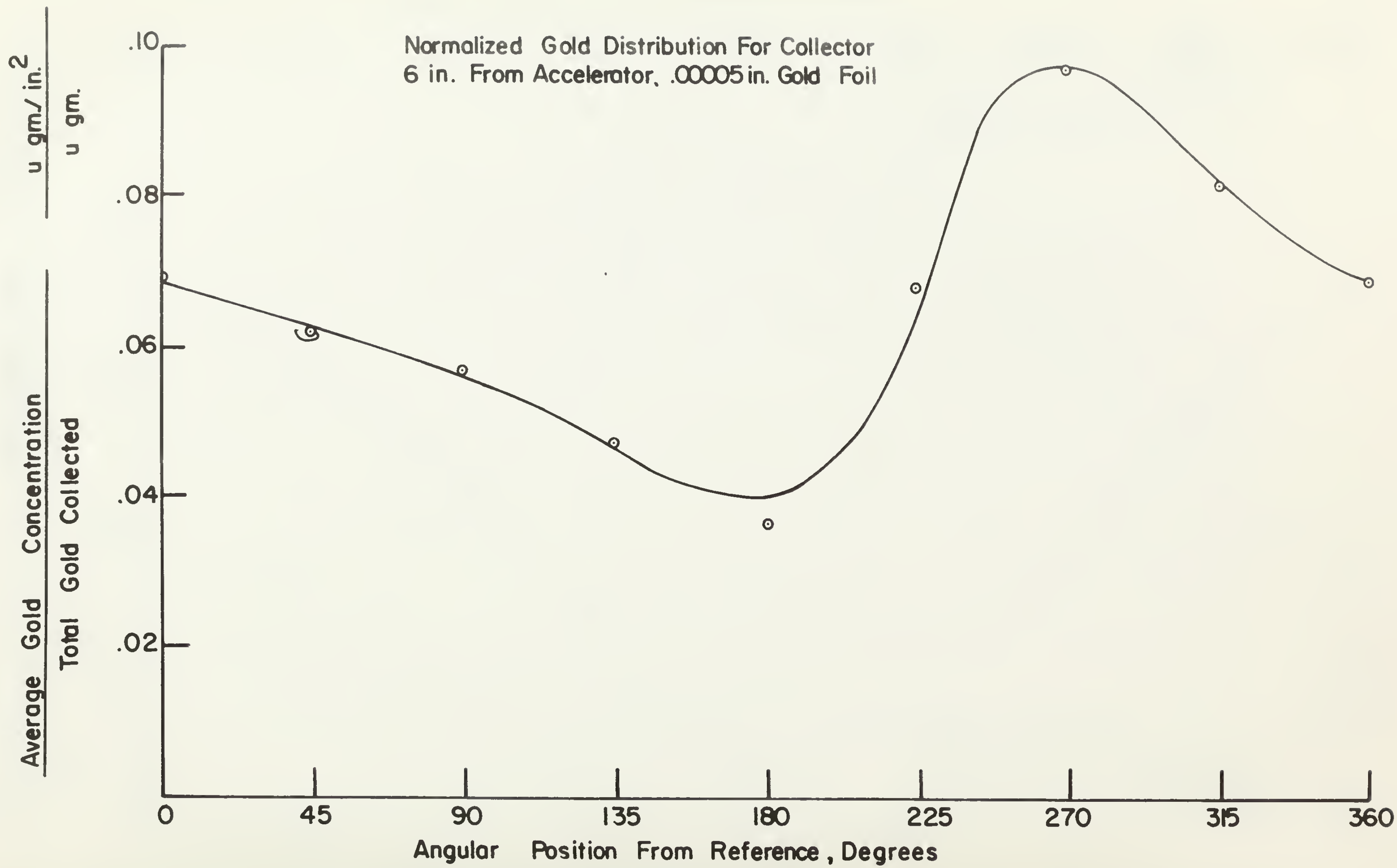
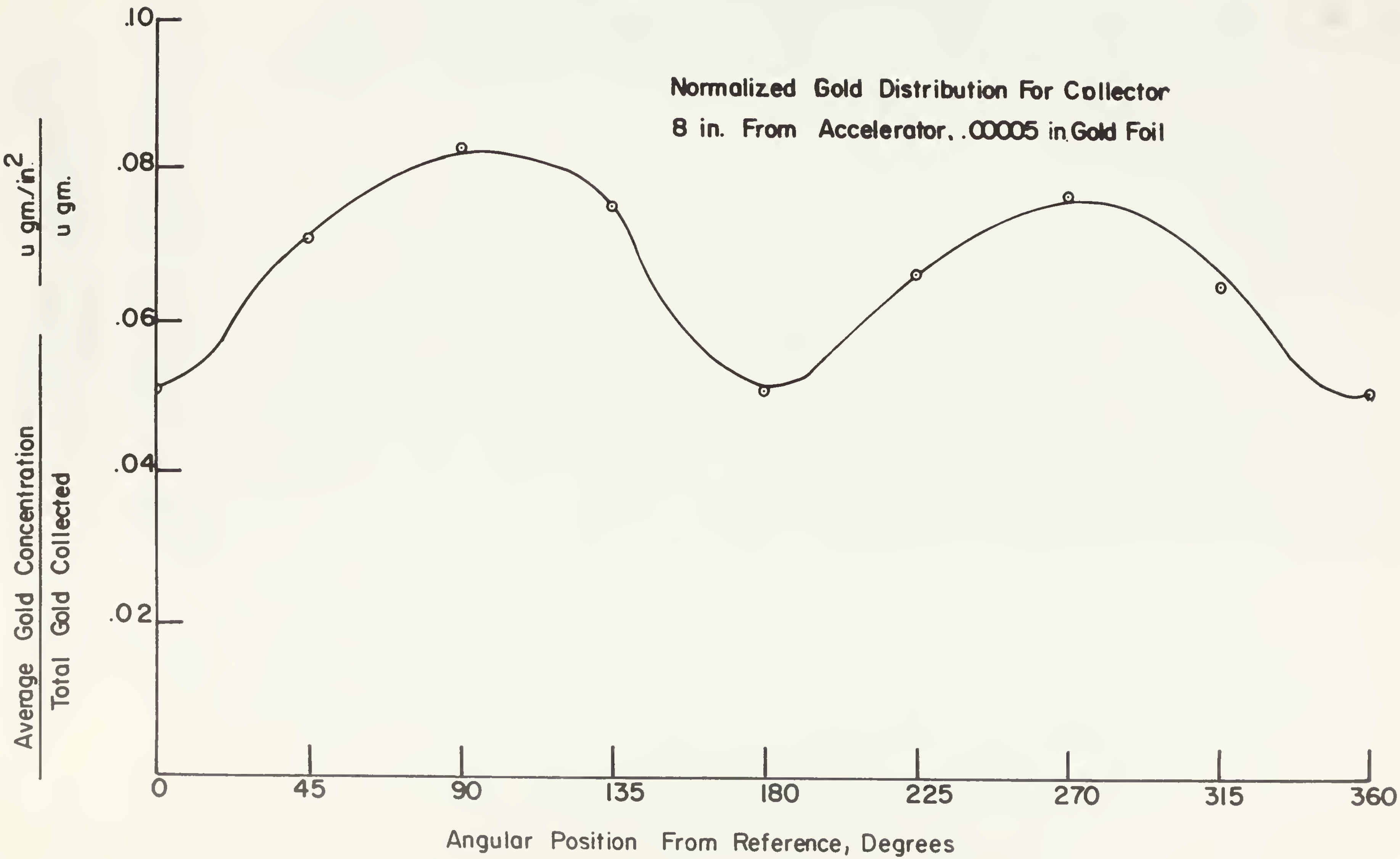

Normalized Gold Distribution For Collector
6 in. From Accelerator, .00005 in. Gold Foil
Average Gold Concentration / Total Gold Collected
u gm/ in.2 / u gm.
.10
.08
.06
.04
.02
0
45
90
135
180
225
270
315
360
Angular Position From Reference, Degrees

FIGURE 32



Normalized Gold Distribution For Collector
8 in. From Accelerator, .00005 in. Gold Foil
.10
.08
.06
.04
.02
0
45
90
135
180
225
270
315
360
Angular Position From Reference, Degrees
Average Gold Concentration / Total Gold Collected
u gm./in.^{2} / u gm.

FIGURE 33

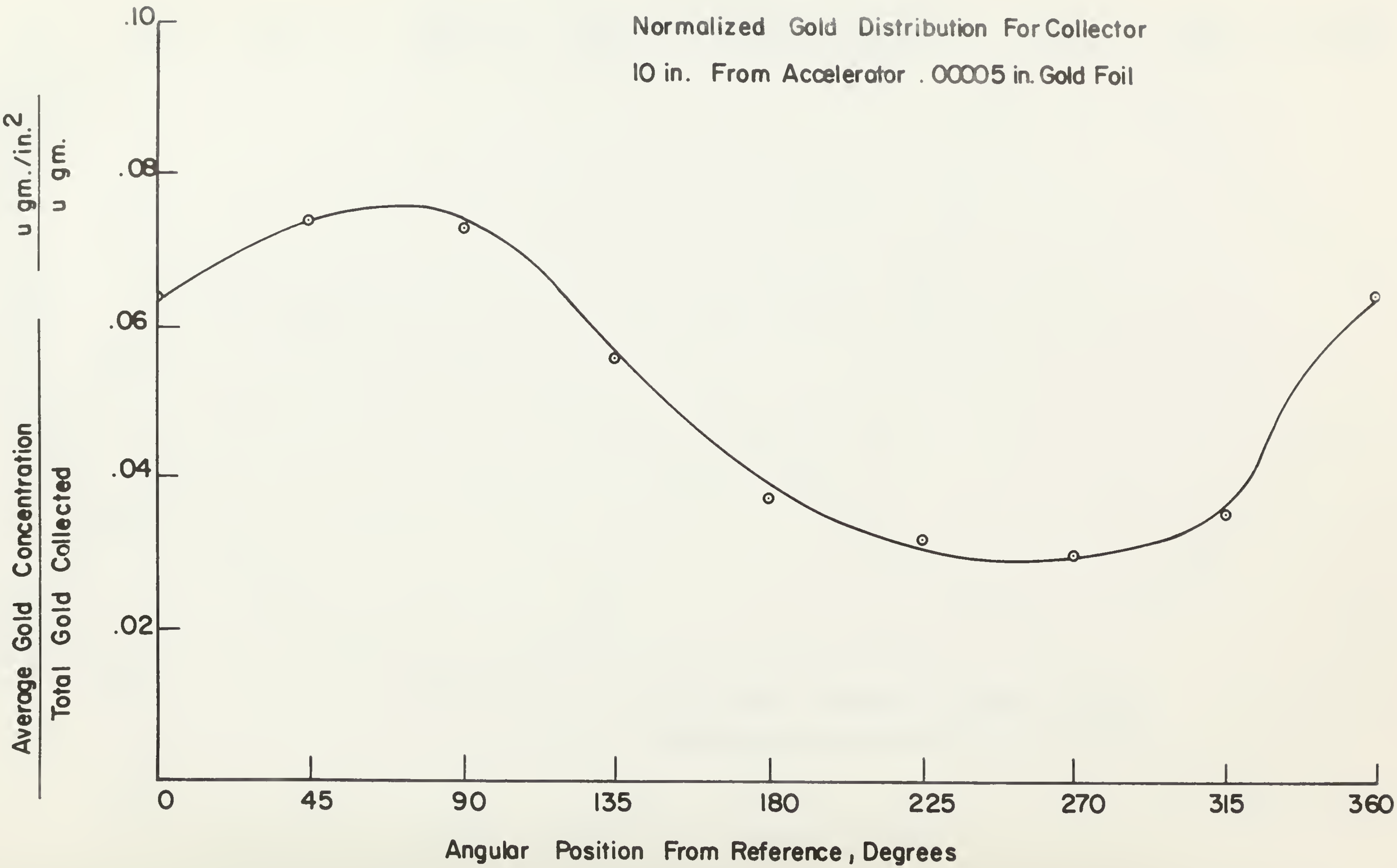
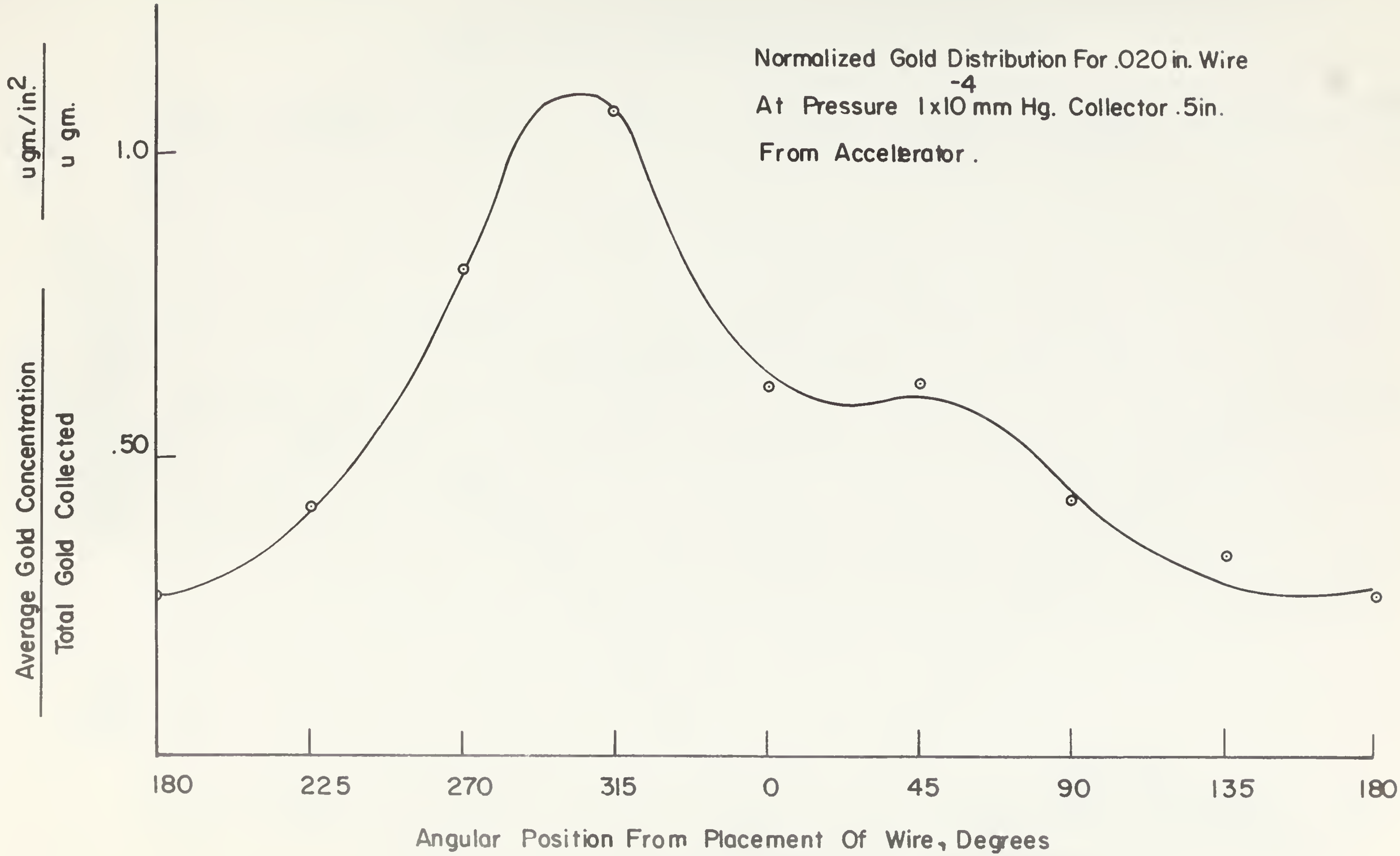
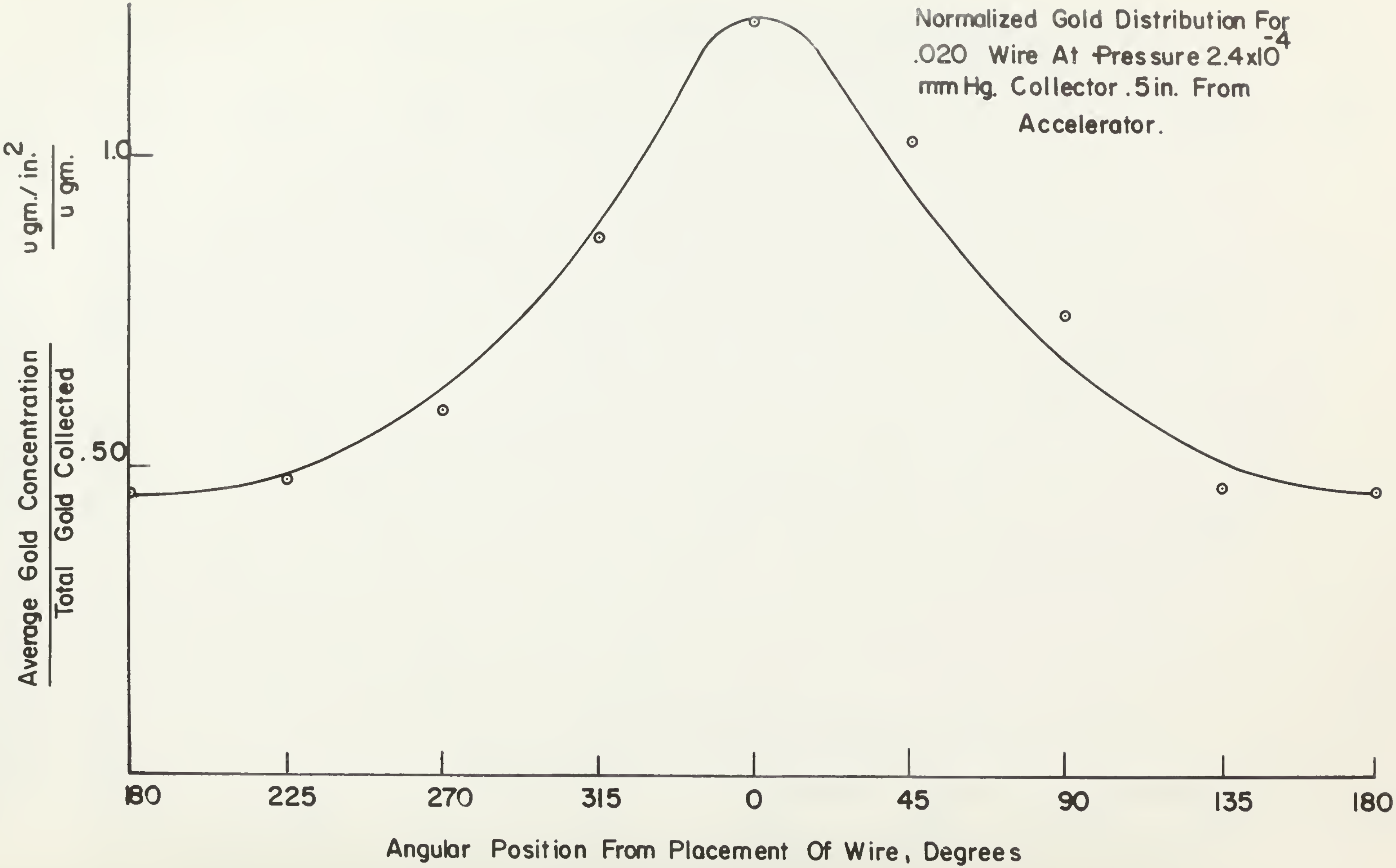

Normalized Gold Distribution For Collector
10 in. From Accelerator .00005 in. Gold Foil
Average Gold Concentration / Total Gold Collected
u gm./in.2 / u gm.
.10
.08
.06
.04
.02
0
45
90
135
180
225
270
315
360
Angular Position From Reference, Degrees

FIGURE 34



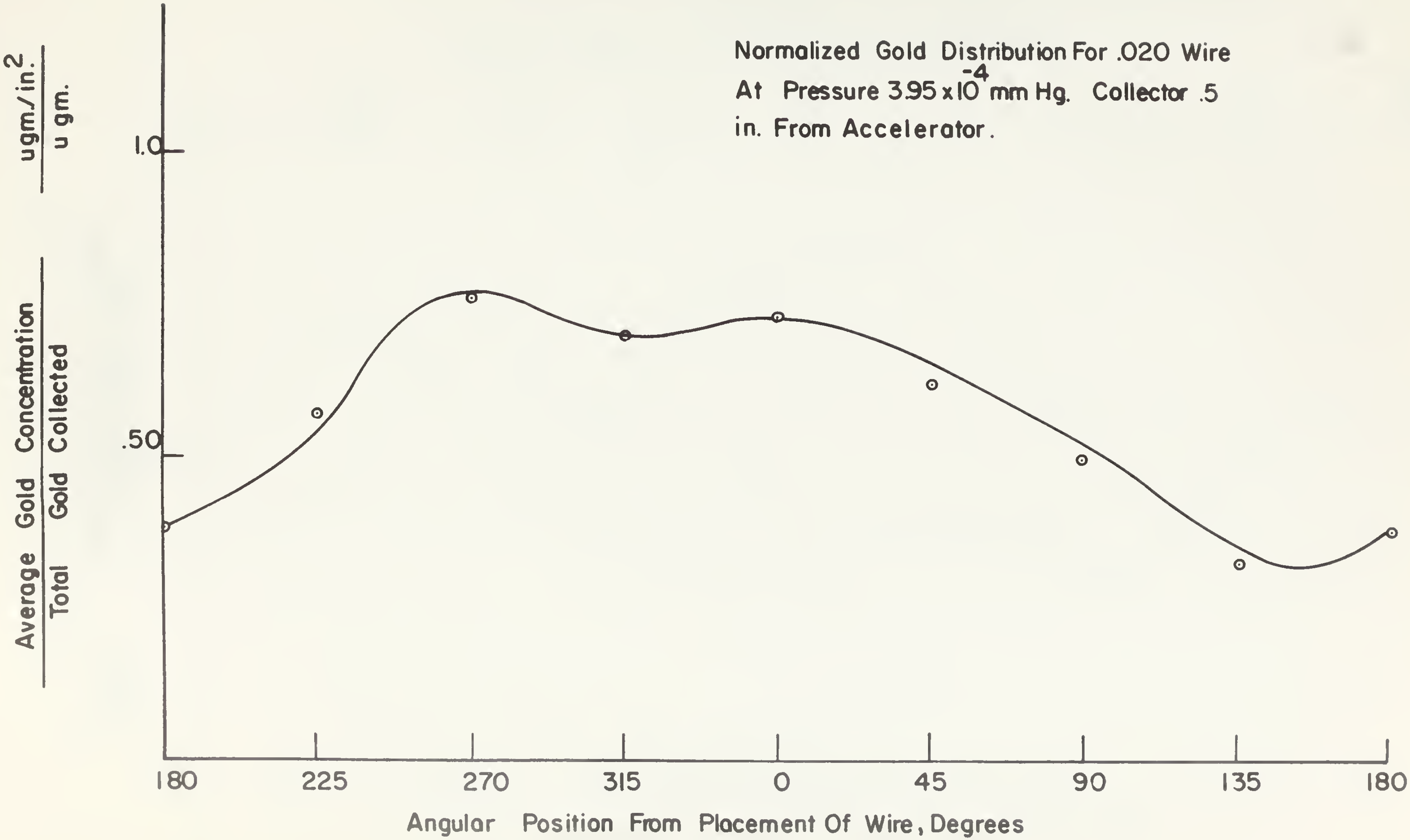
Normalized Gold Distribution For .020 in. Wire
At Pressure 1x10 -4 mm Hg. Collector .5in.
From Accelerator.
Average Gold Concentration / Total Gold Collected
ugm./in.2 / u gm.
1.0
.50
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 35



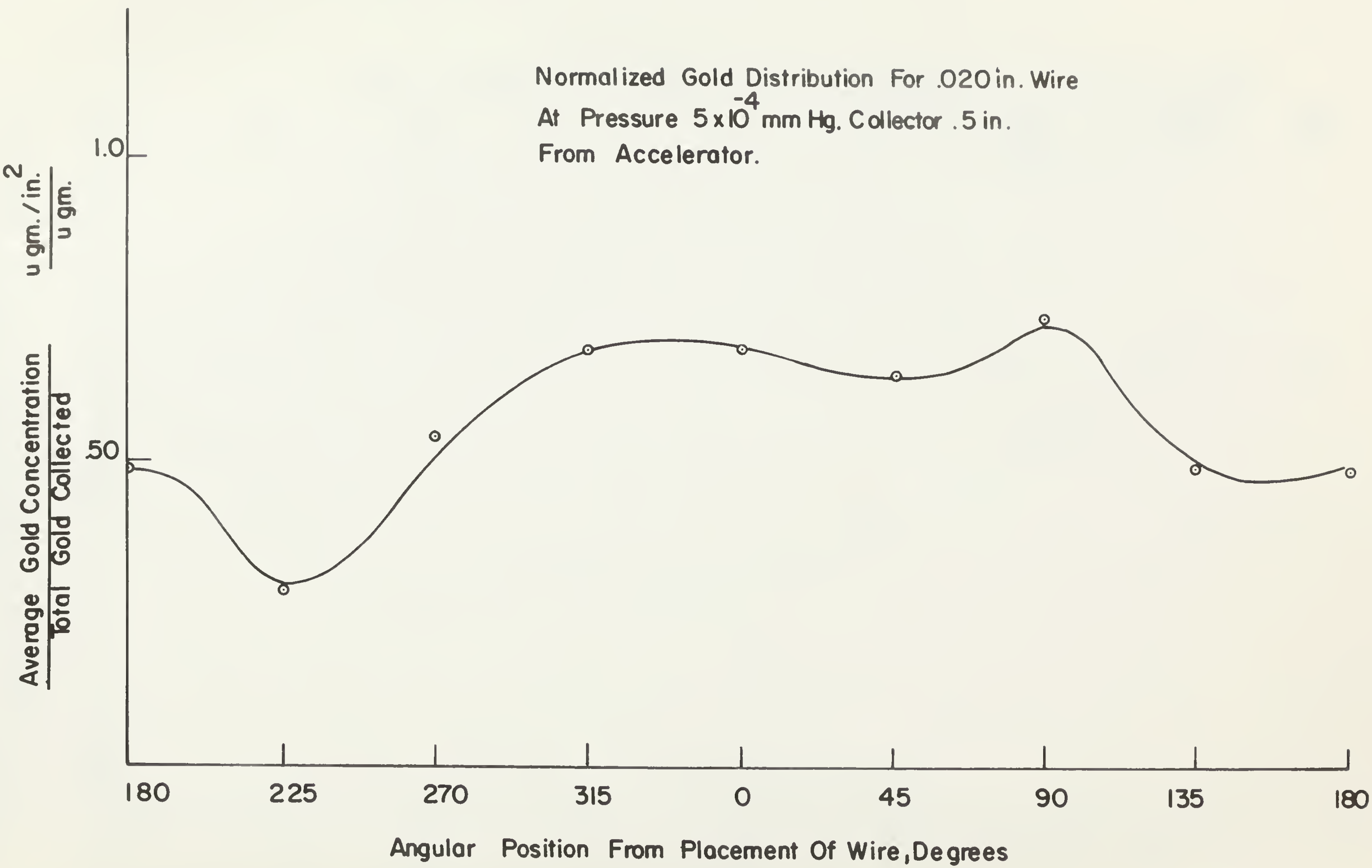
Normalized Gold Distribution For
.020 Wire At Pressure 2.4x10^-4
mm Hg. Collector .5 in. From
Accelerator.
Average Gold Concentration / Total Gold Collected
u gm./in.^2 / u gm.
1.0
.50
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 36



Normalized Gold Distribution For .020 Wire
At Pressure 3.95 x 10^-4 mm Hg. Collector .5
in. From Accelerator.
1.0
.50
Average Gold Concentration / Total Gold Collected
ugm/in.^2 / u gm.
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 37



Normalized Gold Distribution For .020 in. Wire
At Pressure 5 x 10^-4 mm Hg. Collector .5 in.
From Accelerator.
Average Gold Concentration / Total Gold Collected
u gm./in.^2 / u gm.
1.0
.50
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 38

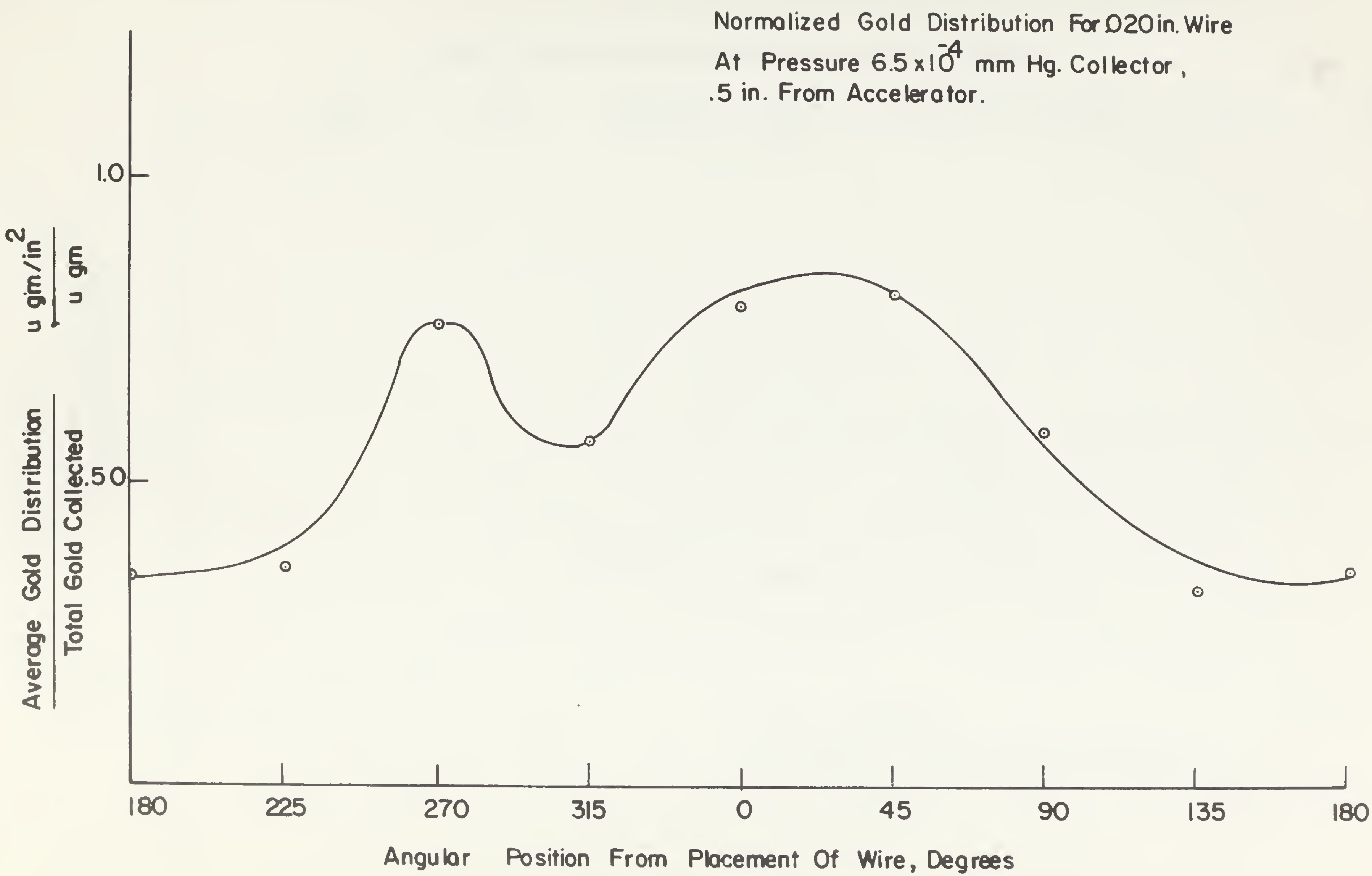

Normalized Gold Distribution For .020 in. Wire
At Pressure 6.5 x 10^{-4} mm Hg. Collector, .5 in. From Accelerator.
1.0
.50
Average Gold Distribution / Total Gold Collected
u gm/in^2 / u gm
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 39

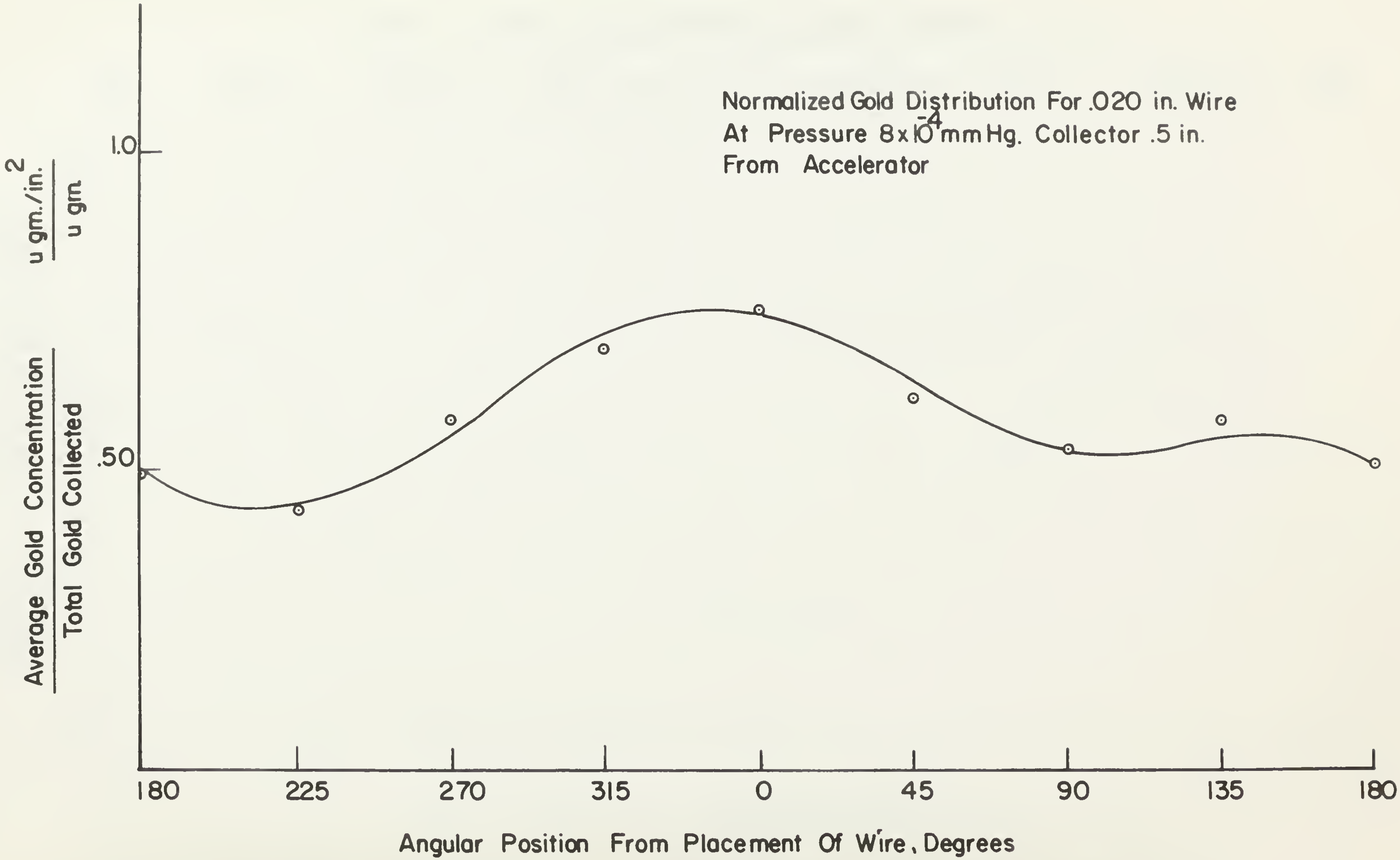
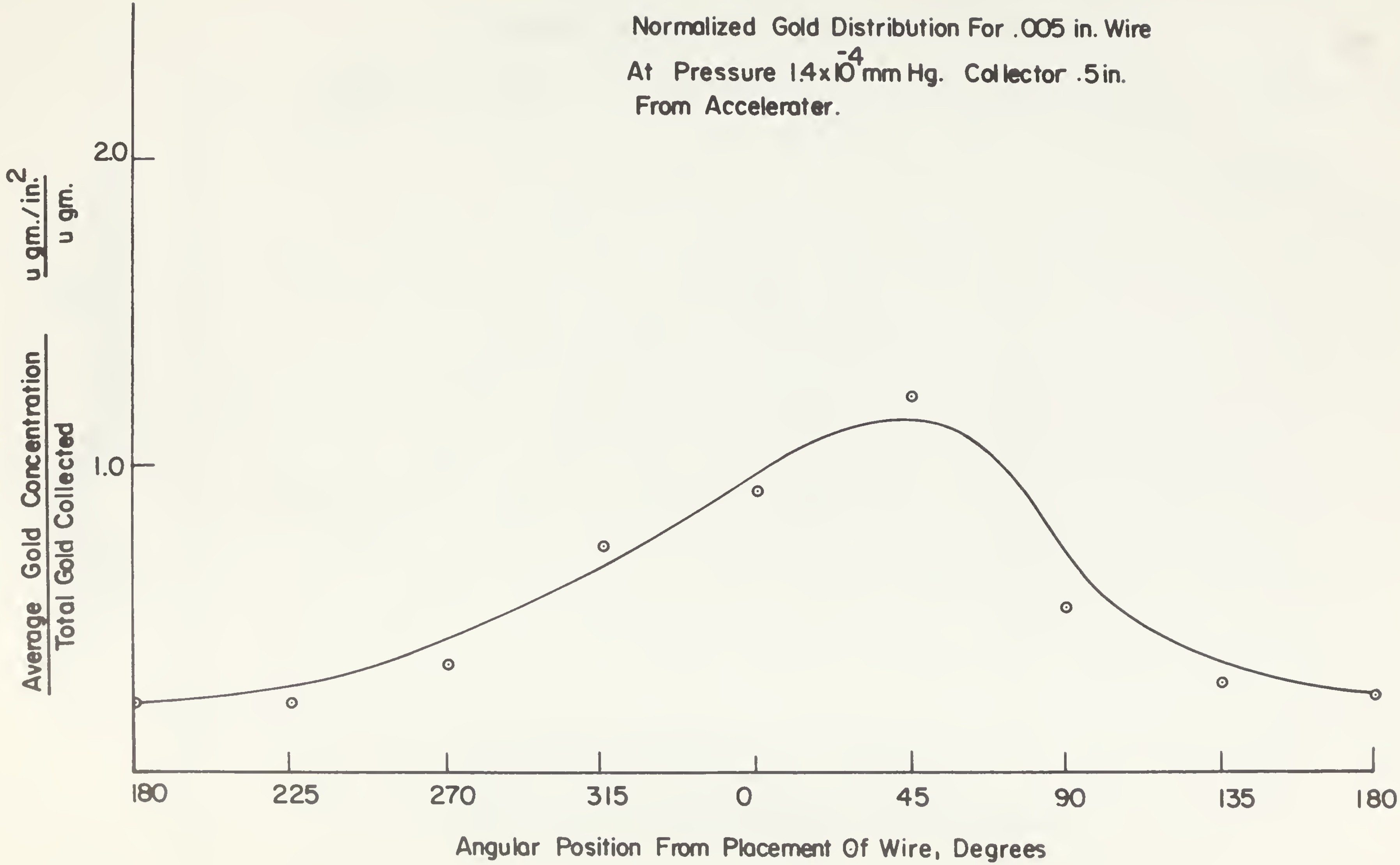

Normalized Gold Distribution For .020 in. Wire
At Pressure 8x10-4 mmHg. Collector .5 in.
From Accelerator
Average Gold Concentration / Total Gold Collected
u gm./in.2 / u gm.
1.0
.50
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 40


Normalized Gold Distribution For .005 in. Wire
At Pressure 1.4x10-4 mm Hg. Collector .5 in.
From Accelerater.
Average Gold Concentration / Total Gold Collected
u gm./in.2 / u gm.
2.0
1.0
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees
FIGURE 41

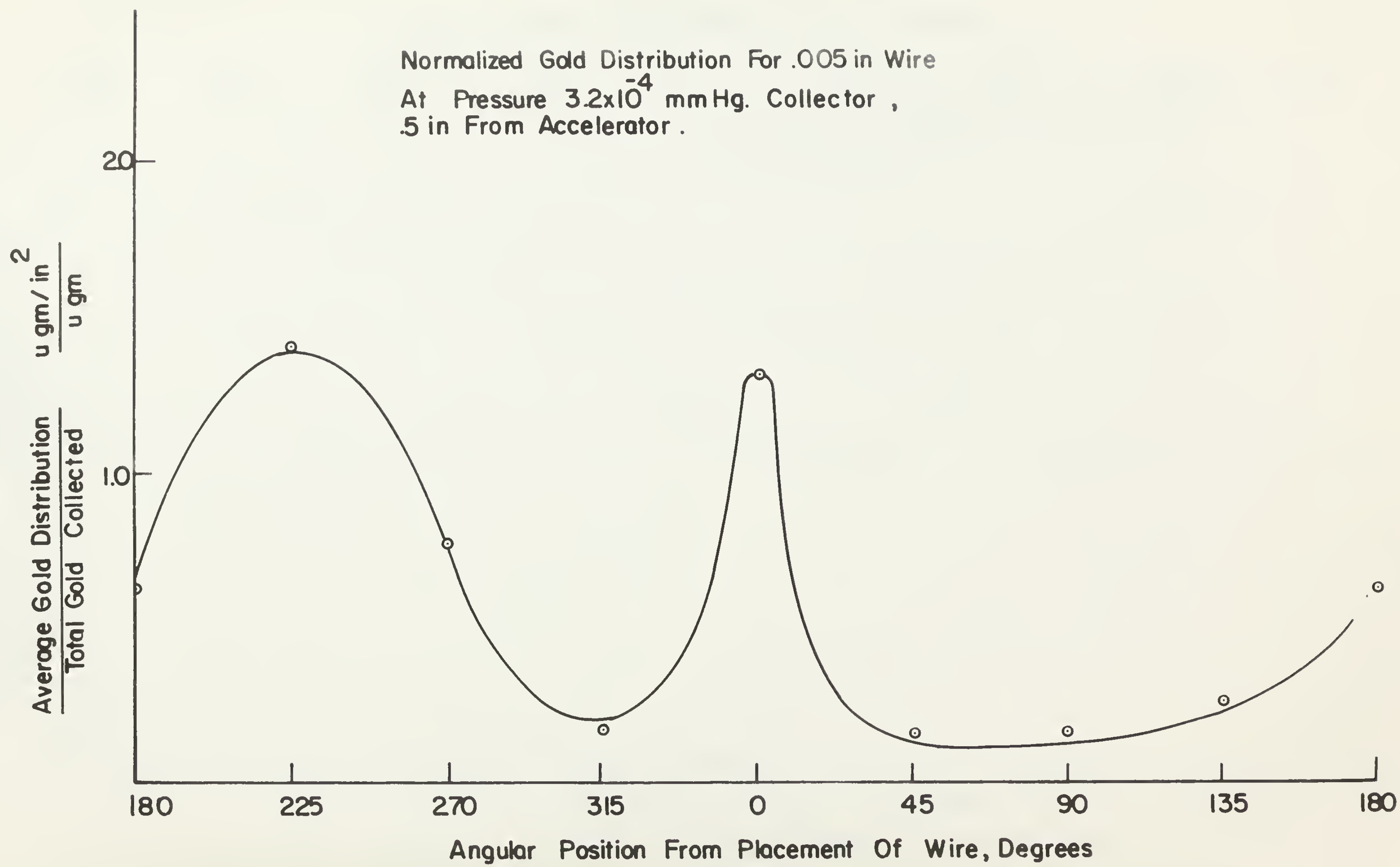

Normalized Gold Distribution For .005 in Wire
At Pressure 3.2x10^-4 mm Hg. Collector,
.5 in From Accelerator.
2.0
1.0
Average Gold Distribution / Total Gold Collected
u gm/in^2 / u gm
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 42

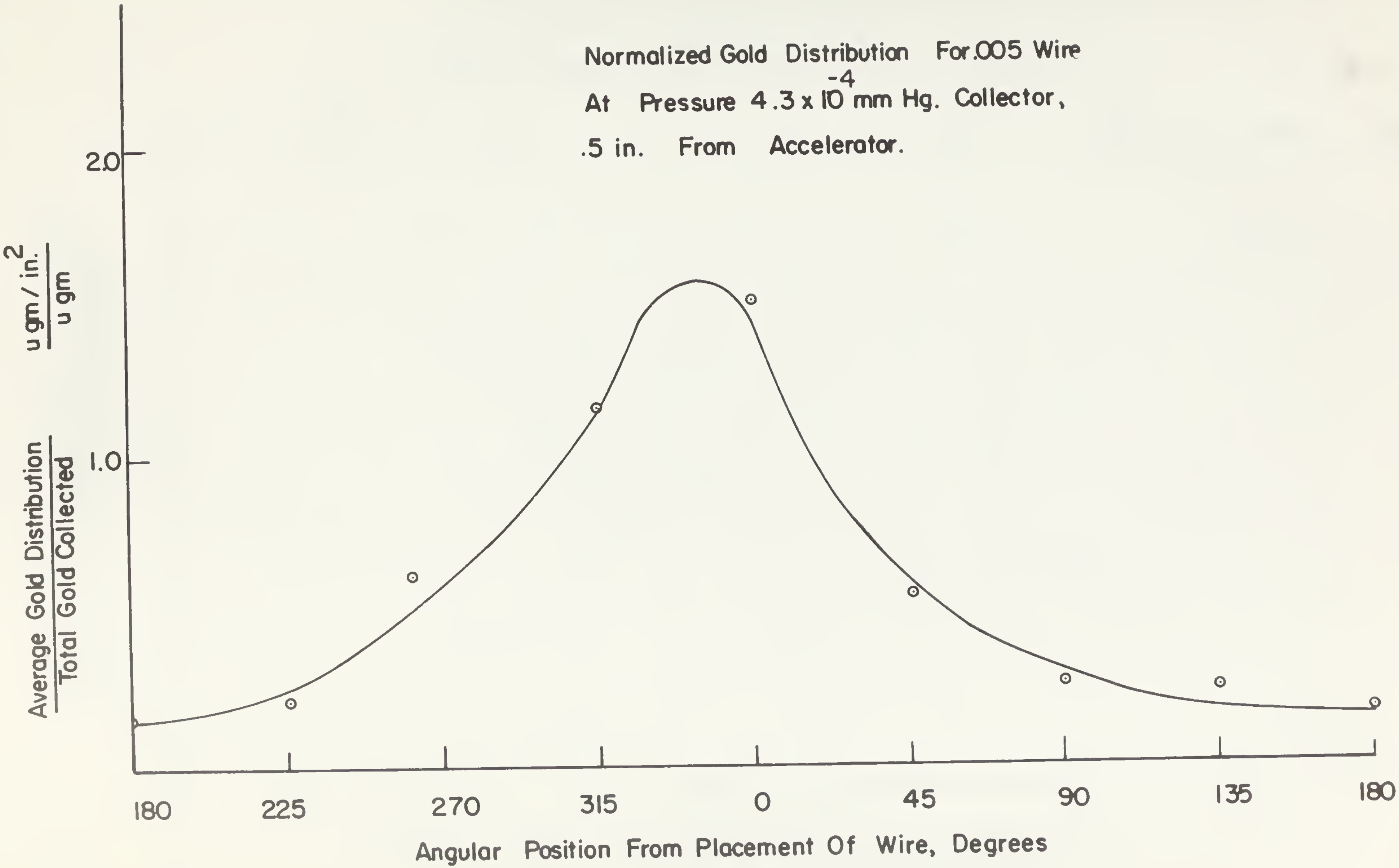
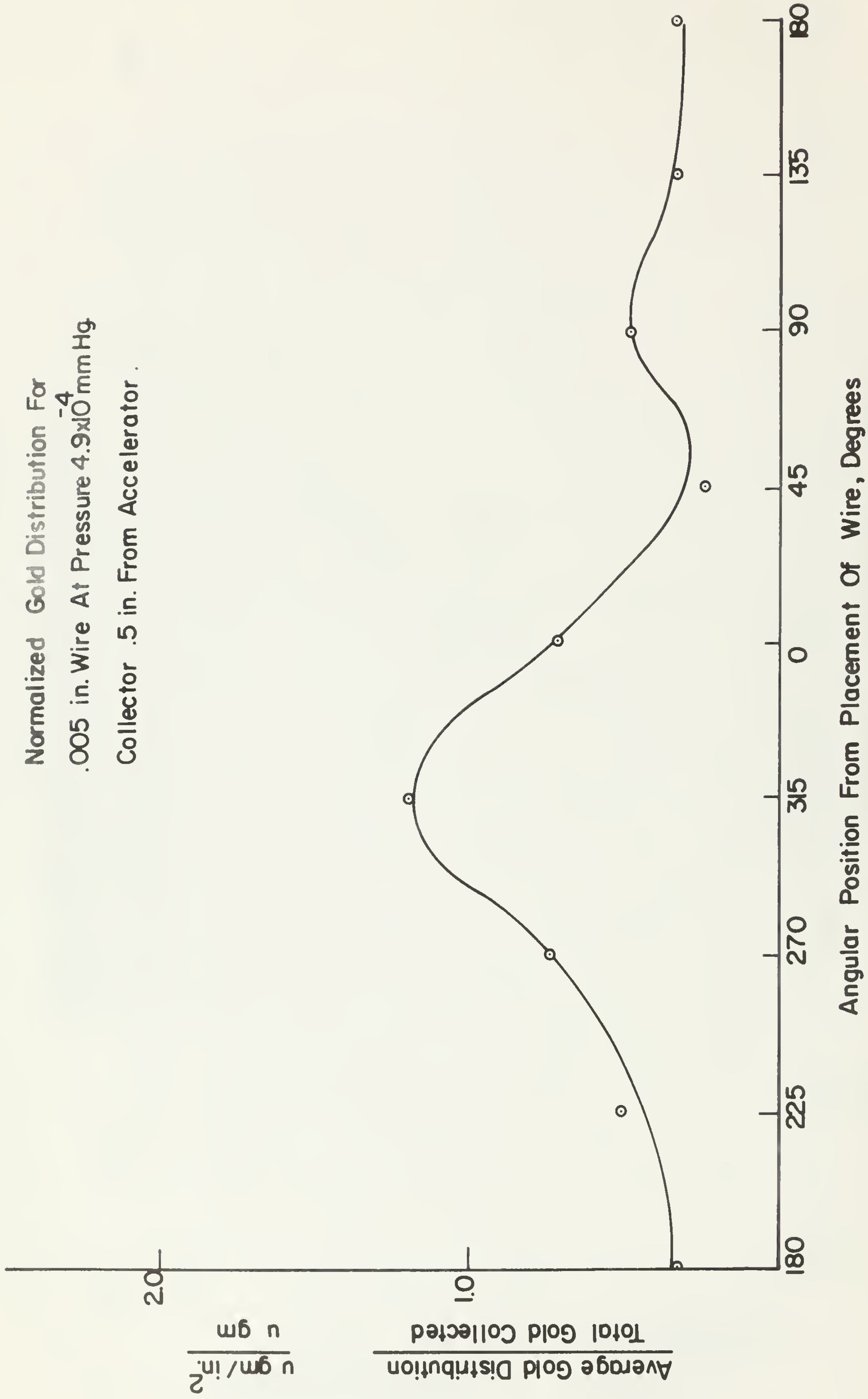
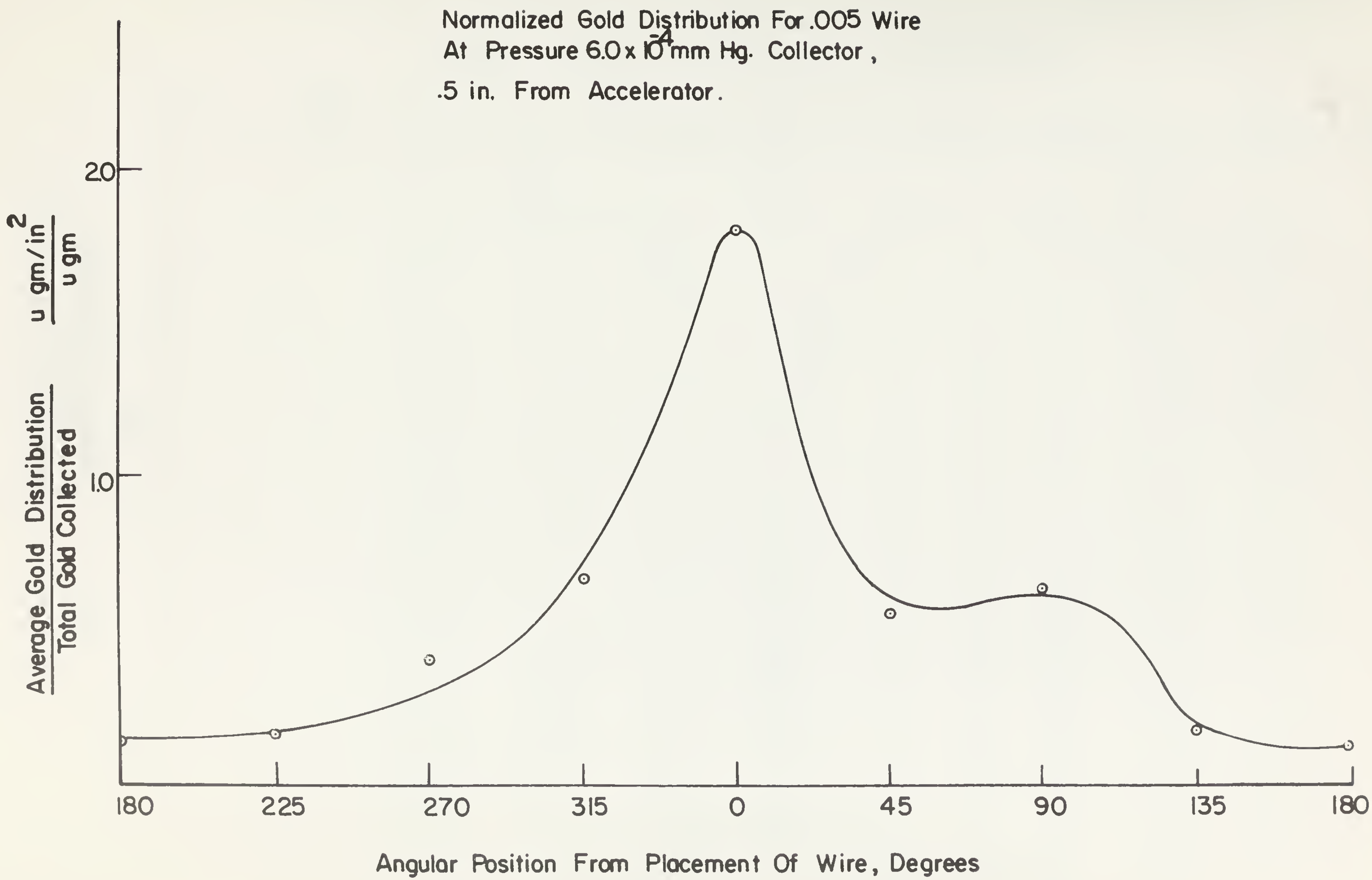

Normalized Gold Distribution For .005 Wire
At Pressure 4.3 x 10^-4 mm Hg. Collector,
.5 in. From Accelerator.
Average Gold Distribution / Total Gold Collected
u gm / in.^2 / u gm
2.0
1.0
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 45



Normalized Gold Distribution For
.005 in. Wire At Pressure 4.9x10^{-4} mm Hg
Collector .5 in. From Accelerator.
Average Gold Distribution / Total Gold Collected
u gm/in.^{2} / u gm
2.0
1.0
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 44


Normalized Gold Distribution For .005 Wire
At Pressure 6.0 x 10-4 mm Hg. Collector,
.5 in. From Accelerator.
2.0
1.0
u gm/in2 / u gm
Average Gold Distribution / Total Gold Collected
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE

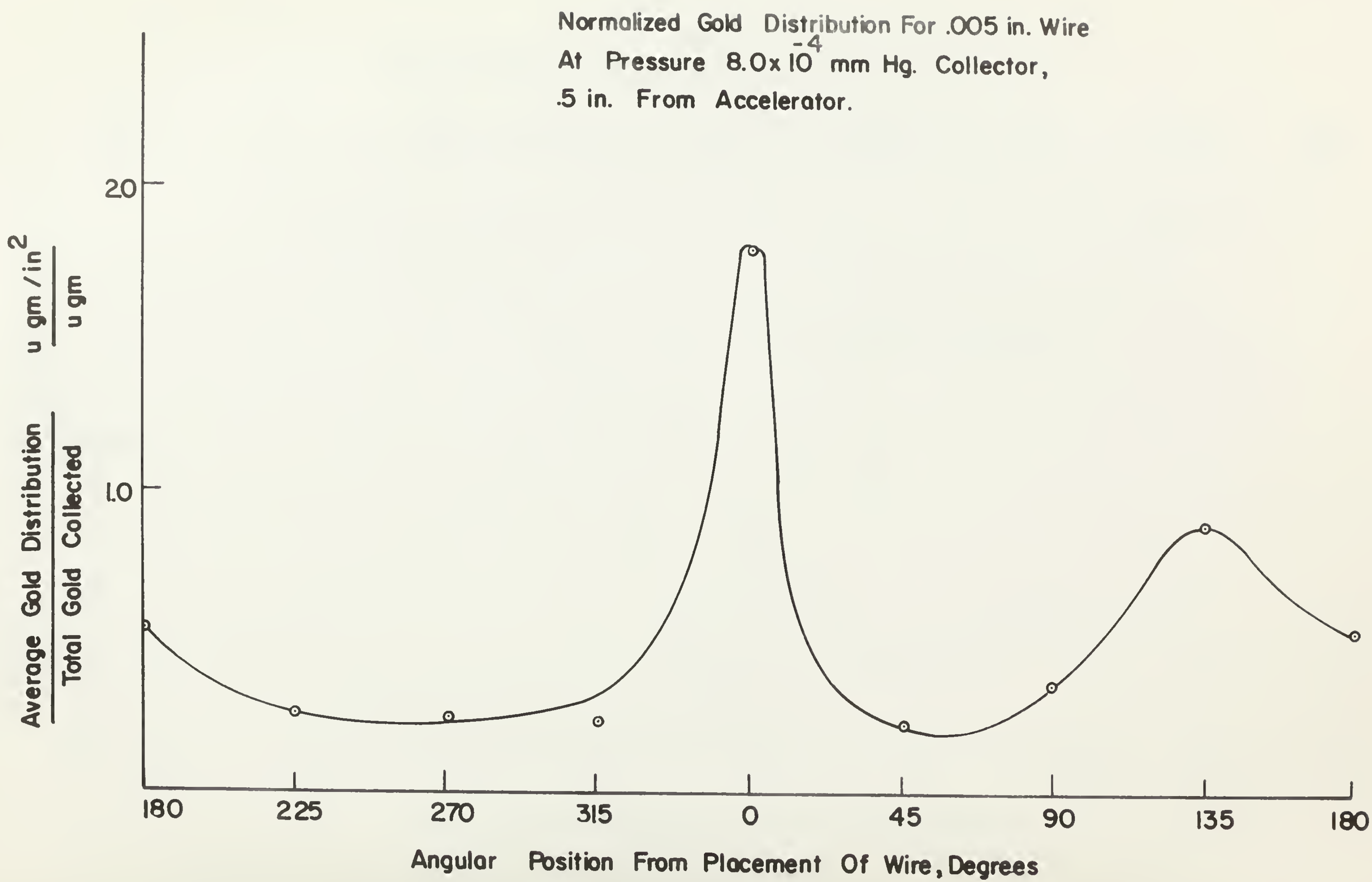

Normalized Gold Distribution For .005 in. Wire
At Pressure 8.0x10^-4 mm Hg. Collector,
.5 in. From Accelerator.
Average Gold Distribution / Total Gold Collected
u gm/in^2 / u gm
2.0
1.0
180
225
270
315
0
45
90
135
180
Angular Position From Placement Of Wire, Degrees

FIGURE 46

BIBLIOGRAPHY

1. Bostick, W. H., "Hall Currents and Vortices in the Coaxial Plasma Accelerator," The Physics of Fluids, v. 6, pp. 1598-1603, November 1963.

2. Brumwell, Robert K., Radioisotope Tracing of Metallic Deposits Near a Coaxial Plasma Gun Exhaust, M. S. Thesis. U. S. Naval Postgraduate School, 1966.

3. Ferraro, V. C. A., and Plimpton, C., Magneto-Fluid Mechanics, Oxford University Press, 1961.

4. Halliday, David, Introduction to Nuclear Physics, John Wiley & Sons, Inc., 1950.

5. Lyon, William S., Guide to Activation Analysis, D. Van Nostrand Company, Inc., 1964.

6. National Aeronautics and Space Administration Technical Memorandum X-1600, Coaxial Plasma Gun Research at Lewis Research Center, by Charles J. Michels, July 1968.

7. Powers, William E., "Measurements of the Current Density Distribution in the Exhaust of an MPD Arcjet,""AIAA Journal, v. 5, pp. 545-550, March 1967.

8. Reitz, John R., and Milford, Frederick J., Foundations of Electromagnetic Theory, Addison-Welsey Publishing Company, Inc., 1960.

9. Smith, Michael J., An Experimental Investigation of the Effects of Environmental Pressure on the Exhaust of a Coaxial Plasma Gun, M. S. Thesis, U. S. Naval Postgraduate School, 1968.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library Naval Postgraduate School Monterey, California 93940	2
3.	Commander, Naval Air Systems Command Department of the Navy Washington, D. C. 20360	1
4.	Commandant of the Marine Corps (Code AO3C) Headquarters, U. S. Marine Corps Washington, D. C. 20380	1
5.	James Carson Breckinridge Library Marine Corps Development and Educational Command Quantico, Virginia 22134	1
6.	Professor D. C. Wooten Department of Aeronautics Naval Postgraduate School Monterey, California 93940	1
7.	Professor Oscar Biblarz Department of Aeronautics Naval Postgraduate School Monterey, California 93940	1
8.	2nd LT Robert D. Strouse, USMC 210 San Fernando Blvd. Savannah, Georgia 31406	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Postgraduate School Monterey, California 93940	Unclassified
	2b. GROUP

3. REPORT TITLE

An Experimental Investigation of the Mass Distribution from the Exhaust of a Coaxial Plasma Accelerator

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; June 1969

5. AUTHOR(S) (First name, middle initial, last name)

Robert Dale Strouse

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1969	74	9

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

Investigations were conducted on the mass distribution of the exhaust of a coaxial plasma accelerator in order to gain insight into the manner by which the fuel (gold) is ionized and accelerated. Tests were conducted using both annular sections of gold foil and single strands of gold wire. Both types of runs showed a non-uniform angular distribution with one or more well defined peaks. The similarity between the distributions leads to the probable conclusion that the foil, rather than undergoing uniform ionization around the annulus, is actually ionizing at discreet "spokes" about its periphery. Experiments conducted with gold foil involved varying the distance from the accelerator to the collector. A fairly uniform dispersion of gold plasma was observed as collector distance increased.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Coaxial						
Plasma						

thesS854
An experimental investigation of the mas
3 2768 002 02135 4
DUDLEY KNOX LIBRARY