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CONTRACT NO. 951477

FINAL REPORT

THE DEVELOPMENT OF HIGH RESOLUTION, HIGH STABILITY STERILIZABLE IMAGE DISSECTOR TUBES

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Contract No. 951477

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

1. INTRODUCTION

The purpose of this program was to improve the electron-optical performance and stability of bi-alkali image dissectors in sterilized applications and to determine the long term performance of bi-alkali image dissectors which have and have not been sterilized. A complete test specification was to be developed for the wide angle bi-alkali image dissector tube.

The program was divided into five phases. Phase I, a review of bi-alkali photocathode data and electron-optical calculations. Phase II, electron-optical experiments, and Phase V, bi-alkali photocathode study, were completed. Phase V was added during the course of the program. Phase III, sterilization tests, and a portion of Phase IV, life tests were not completed.

2. SUMMARY

Image dissector test specifications and test summary sheets were generated for use with new test equipment supplied by J.P.L.

The test specifications included:

1. Instructions for performing each test.
2. Data presentation format sheets with sample calculations for obtaining test data, and
3. Test data summary.

The image section characteristics of the dissector tube were analyzed and experiments were performed to determine the effects of changes on electron-optical performance of the tube.

Evaluation of these experiments yielded the following information:

1. The pincushion distortion is not a problem in the image dissector of present design.
2. Some degradation of resolution occurs in the deflection process.
3. Deflection sensitivity decreases with the increase of deflection diameter as calculated.
4. Increased cathode-focus electrode spacing has little or no effect on the focusing characteristics or resolution of the tube.

5. The reduction of cathode-focus electrode spacing has an adverse effect on image section focusing properties.
6. Increased radius of cathode curvature causes some degradation of resolution.
7. Decreased radius of cathode curvature has no effect on resolution.

Based on these results and on calculations estimating the electron trajectories of the normally emitted electrons through the no-drift integrated ceramic anode deflection cone, a new truncated, high sensitivity deflectron was designed and made.

The limited electron-optical experiments investigated during the program indicate that the performance of the image dissector of present design is near optimum. The changes in the design of the image section, introduced in the experiments, did not contribute to any significant improvement of the electronic resolution. It is believed that the electronic resolution of the tube is inherent in the basic design of the image section and that a completely new design approach would be in order to achieve any significant improvement. An appreciably improved resolution was obtained only in experimental tubes employing long (.450" x .030") electron aperture, but only when the electronic spot was displaced along the aperture or in close proximity of the aperture . Displacement of the spot in any other direction resulted in resolution similar to that of standard image dissectors. To determine whether or not the spot size variation, which occurs during deflection of the spot along and near the aperture is due to an aperture effect further investigation would be required. The design work on the new truncated anode/deflection cone indicates the feasibility of using such a deflection system in the image dissector which would result in improved deflection sensitivity.

In addition to the electron-optical study, a major part of this program was devoted to the development of techniques required to produce thermally sterilizable bi-alkali photocathodes. This is a photocathode in which the luminous sensitivity and the uniformity of sensitivity change less than 10% per thermal cycle (one thermal cycle = 92 hours, 135°C bake). Since, for mechanical reasons, certain restrictions were placed on the choice of substrate materials, 0122 glass, 7056 glass and sapphire were evaluated in this program. The use of 7056 glass was discontinued early in the program due to generally inferior results. The bi-alkali photocathode formed on

0122 soda lime glass performed better than those on sapphire substrates, although it was believed that due to non-reactive properties of sapphire this would not be the case. The experiments performed demonstrated that a minimum luminous sensitivity of not less than 20 microamperes per lumen is a very realistic performance figure after numerous thermal cycles. To achieve this, an initial thermal cycle is included in the manufacturing procedure.

A 20 microampere per lumen bi-alkali photocathode would have a 0.024 ampere per watt peak response which occurs between 400-450 nanometers. This compares favorably with a 30 microampere per lumen S11 photocathode, which has a peak sensitivity of 0.021 ampere per watt at 450 nanometers.

The random and localized decay in sensitivity, and therefore increased non uniformity occuring during thermal cycling, was found to be caused mainly by:

1. Reaction of cathode elements with the cathode substrate. This includes diffusion of the cathode elements into the glass and vice versa, and
2. Reaction with the residual contaminants on the substrate surface.

The limited experiments undertaken indicate that the performance of a photocathode has to be considered in conjunction with the substrate and that the use of highly stable substrates materials does not necessarily ensure good cathode stability. It is evident that interaction between the cathode, substrate and the resulting complex is of great importance in the design of thermally stable photocathodes.

3. TECHNICAL DISCUSSION

3.1 Phase I

The report on Phase I was submitted to J.P.L. on August 9, 1966, and is attached to this document as Appendix I.

3.2 Phase II

The results of measurements performed under J.P.L. Contract No. 950784 indicated that the rapid increase of the electronic spot size at points greater than 0.3 inches from the tube axis was partially due to distortion of the electron beam originating at the peripheral areas of the photocathode. To determine the effect of the image section components on the electron beam distortion the following experiments were designed:

A. Use of a large diameter deflectron to determine the effects of fringe fields at the apex of the deflectron.

B. Use of a pincushion corrected deflectron to evaluate the pincushion distortion of the image dissector.

C. Use of a long aperture, one end of which lies on the axis of the tube, to investigate the effect of the deflectron on electronic resolution of the image section. In this experiment the electronic spot size was measured without deflecting the electron beam into the center of the aperture.

D. Use of a long focus electrode to investigate the effect of a reduced photocathode-focus electrode spacing on resolution.

E. Use of a short focus electrode to evaluate the effect of increased cathode-focus electrode spacing on resolution.

F. Use of faceplates with increased and decreased radii of curvature to investigate the effect of faceplate curvature on resolution.

3.2.1 Large Diameter Deflectron

A total of six bi-alkali image dissectors, incorporating large diameter anode/deflection cones were assemblied and processed. Two of the image dissectors, No. 1389 and No. M1390, used large diameter deflectrons designed to reduce pincushion distortion. All the tubes, except one, No. M1363, were tested and the test results are shown in Table I. Tube No. M1363 was not tested due to very low photocathode sensitivity caused by a leak in the faceplate frit seal.

Electronic spot size measurements were made on tubes M1364, M1380 and M1390. Image distortion measurements were made on tubes M1383 and M1389, the last using a pincushion corrected large diameter deflectron. Figures 1 through 3 show the electronic spot size variations as a function of displacement from the center of the photocathode. The variations in the electronic spot size of all three tubes, employing large diameter deflectrons, does not differ from electronic spot size obtained under previous programs where standard size deflectrons were used. The results obtained with the three tubes indicate that the diameter of the deflectron apex is not a major cause of the deterioration of the electron spot size which occurs in the peripheral areas of the photocathode.

Figures 4 and 5 show image section distortion of tubes M1383 and M1389. A very small amount of pincushion distortion is evident in both figures indicating that the design change of the deflectron in tube M1389 had little if any effect at all. Deflection linearity of tubes M1364 and M1383 is shown in Figures 6 and 7. As indicated, the deflection linearity of tubes with large deflectrons is slightly worse than that obtained with tubes employing standard diameter anode/deflectron cones.

The results listed in Table I indicate that the deflection sensitivity of the large diameter deflectron by 18%. This value compares favorably with the theoretical value of 15%. A further decrease in deflection sensitivity of the pincushion corrected large diameter deflectron was expected since the pincushion correction involves a decrease in the active area of the deflection plates.

3.2.2 <u>Effect of deflection on resolution - long aperture deflectron</u>

Two image dissectors designed for resolution evaluation were

TABLE I

Tube No.	M 1364	M 1383	M 1380	M 1389[xx]	M 1390[xx]
Electronic Aperture Size	.006 x .156"	.004 dia.	.032x.165	.004" dia.	.032x.166
Photocathode Sensitivity uA/lumen	40	36	45	45	40
Photocathode Uniformity %	90	37.5	61	71	72
Dynode Uniformity %	----	----	82	----	87
Multiplier Gain at 125 Volts/Stage	9.4×10^5	9.5×10^6	7.5×10^6	9.0×10^6	1.3×10^7
Anode Dark Current uA	0.01	0.0058	0.012	0.004	0.012
Deflection Sensitivity inches/Volt*		0.00149		0.0013	
Aperture Plate Misalignment			9°		11°

* Image section voltage = 700 Volts

xx Tubes employing pincushion corrected deflectrons assembled and processed. Tubes No. M1409 and M1439 had apertures .030 x .450 inches, one end of which was on the axis of the tube.

In both tubes the electronic spot size was measured with and without deflecting the electrons into the center of the tube. Figures 8 and 9 show the electronic spot size variations as a function of displacement from the center at various focus electrode potentials. For the tube No. M1409, the curves of Figure 8 were obtained without deflection and those of Figure 9 with deflection. It is evident from both figures, that the minimum spot size was obtained when the focus electrode potential was at 46 volts with respect to the photocathode. The spot sizes for both the deflected and undeflected electrons were similar (.0035 to .004") at points 0", 0.1" and 0.2" in both tubes. At points 0.3" and 0.4" the spot sizes were: for deflected electrons 0.005" and 0.008" and for undeflected electrons 0.004" and 0.006".

The corresponding values for tube M1439 were .0045", .0065 and .0035, .0060". The difference in spot size of deflected and undeflected electrons indicates that the use of deflection voltage tends to lower the resolution of the image section. When the spot of light was displaced vertically (perpendicular to the long side of the aperture) the variation in electronic spot size was no different from that of image dissectors employing small apertures. A similar variation in electronic spot size occured when the optical input was displaced along the diagonals. The spot size, however, was smaller on the diagonal near the aperture and became larger when it was moved away from the aperture. From the measurements of electronic spot size in both experimental tubes it can be deduced that in every case the spot size was small when displaced along the aperture and that it was the same as in standard image dissector tube with small aperture when displaced vertically or on the diagonal near the long aperture.

Both the aperture and dynode No. 1 are at ground potential. The closest electrode to the aperture is the second dynode which is at about 125 volts with respect to ground. If there was field penetration then this may have affected the electronic spot size in the long aperture tubes.

To determine whether or not the spot size variations, which occur during deflection of the spot along and across the aperture, are due to an aperture effect a tube with a grid in the aperture was planned.

3.2.3 Variations in photocathode and anode cone to focus electrode spacing.

A total of six image dissectors were made to evaluate the effect of variations in photocathode to focus electrode and, focus electrode to anode cone spacings on tube performance. Tube No.'s M1414 and M1415 had the photocathode-focus electrode spacing reduced by .050" and tubes No.'s M1416 and M1417 had the spacing increased by .050". In the remaining two tubes No.'s M1421 and M1422 the spacing between the anode cone and the adjacent part of focus electrode was increased by .050".

The deflection linearity of tube M1414 (.004" dia. aperture) with lengthened focus electrode, is shown in Figure 10 and the pincushion distortion in Figure 11. In Figure 10 the deflection non-linearity is evident at points 0.4" away from center. The increase in deflection voltage at these points was about 5% on the vertical axis and 4% on the horizontal axis. The reason for high deflection voltage can be attributed to changes in the electric field configuration at the periphery of the photocathode due to decreased cathode-focus electrode spacing. The deflection non-linearity is also evident in Figure 11 showing the equipotential deflection curves. The pincushion distortion in this tube was small and did not differ from those of other experimental tubes.

It was found that the electronic spot size of tube M1415 deteriorated very rapidly when the displacement of the optical input from the tube axis was increased beyond 0.2". By altering the focus potential, E_F, by 10 volts at the .3" inch displacement point and 30 volts at the .4 inch displacement point it was possible to bring these points into focus. The focusing action, however, resulted in a change of position of the electronic image. Figure 12 shows the electronic spot size achievable at each point by adjustment of E_F. The curve is shown for interest only and should not be compared with other electronic spot size curves presented. Those were generated using constant focus potential.

The test results obtained with tubes M1414 and M1415 are given in Table II. Decreasing the photocathode to focus electrode spacing by lengthening the focus electrode has a detrimental effect on the focusing and deflecting properties of the image section.

TABLE II

	M1414	M1415
Electronic aperture inches	.004	.032 x .168"
Photocathode Sensitivity µA/L	43	35
Photocathode Uniformity %	65	47
Multiplier gain at 125 volts stage	1.2×10^7	2.9×10^7
Anode Dark Current at 40A/L	.0017	.0016

Figures 13 and 14 show the deflection linearity and the image distortion of the tube M 1416. In this tube the photocathode/focus electrode spacing was increased by .050 inches by shortening the focus electrode. The performance of the tube was similar to that of tubes using standard focus electrodes.

Increasing the anode cone/focus electrode spacing by increasing the minimum radial dimension of the focus electrode by .050 inches in tubes Nos. M 1421 and M 1422 again caused little if any change in deflection linearity and image distortion. Data on these tubes is shown in Figures 15, 16, 17 and 18.

The electronic spot size measurements of tubes Nos. M 1417 and M 1422 shown in Figures 19 and 20, respectively, indicate that the two experiments involving increases in cathode/focus electrode and anode cone-focus electrode spacing caused only small changes in electronic spot size. The magnitude of the changes being within the variation experienced with standard assemblies.

The test summary of tubes M1416, M1417, M1421 and M1422 is given in Table III.

TABLE III

Tube No.	M1416	M1417	M1421	M1422
Electronic aperture inches	.004	.003x.165	.004	.032x.165
Photocathode Sensitivity µA/L	35	36	52	45
Photocathode Uniformity o/o	74	60	90	50
Multiplier gain at 125 volts/stage	9.9×10^6	8.3×10^6	8.7×10^5	2.4×10^7
Anode Dark Current at 40 A/L	.0018	.003	.0025	.003
Deflection Sensitivity inches/volt*	.00156	.00158	.0016	.0016
Aperture-plate Misalignment		2.3°		1.6°
Dynode Uniformity		80%		88%

* Image section voltage = 700 volts

3.2.4 Variations in radius of curvature of the faceplates.

Two image dissectors with standard (small diameter) anode/deflection cones were assembled and processed. Both tubes were of standard design and employed plano-concave faceplates of different radii of curvatures in order to evaluate the effect of variations in faceplate curvature on electronic spot size. The faceplate in tube No. M1423 had a radius of curvature of 1.348" and the faceplate in No. M1433 had a radius of curvature of 1.216".

Figures 21 and 22 show the electronic spot size variations of tubes M1433 and M1423 respectively. According to the figures the electronic spot size of tube M1423, using a faceplate of increased radius of curvature was larger than that of tube M1433 with a faceplate of decreased radius of curvature. This was most pronounced at points 0.2 and 0.3 inches away from center of the photocathode. At points 0.2 inches from the center the electronic spot size of tube M1423 was 30% larger than that of tube M1433 and at points 0.3 inches from center the increase in spot size of tube

M1423 was 18%. At points 0.4 inches from center, the difference in electronic spot size between the two tubes was only 5%.

Figures 23 and 24 show that the increase or decrease in the radius of curvature of the faceplate did not affect the deflection linearity of the tubes. The test data of tubes M1423 and M1433 is listed in Table IV.

TABLE IV

Tube No.	M1423	M1433
Electronic aperture inches	.032 x .169	.031 x .159
Photocathode sensitivity μA/L	65	40
Photocathode Uniformity %	64	68
Multiplier Gain at 125 Volts/Stage	2.6×10^7	7.0×10^6
Anode Dark Current at 40 A/L	.003	.0025
Deflection sensitivity inches/volt*	.00179	.00179
Aperture-plate misalignment	0.9°	1.2°
Dynode Uniformity %	80	82

* Image section voltage = 700 V

3.3 Phase III and Phase IV

Phase III - the flight acceptance and type approval level sterilization test and Phase IV - 10,000 hour life test were not completed. Phases III and IV were to utilize image dissectors fabricated in Phase II incorporating photocathodes activated according to the process developed in Phases I and V. Since the work on Phase V was extended in time and effort the finalized activation process of bi-alkali photocathodes was not available to be incorporated into the tubes fabricated in Phase II. Test equipment for Phase IV life tests was partially completed.

3.4 Phase V.

Report on Phase V was submitted to JPL on February 2, 1968 and is attached to this document as Appendix II.

ELECTRONIC SPOT SIZE
Tube No. M1364

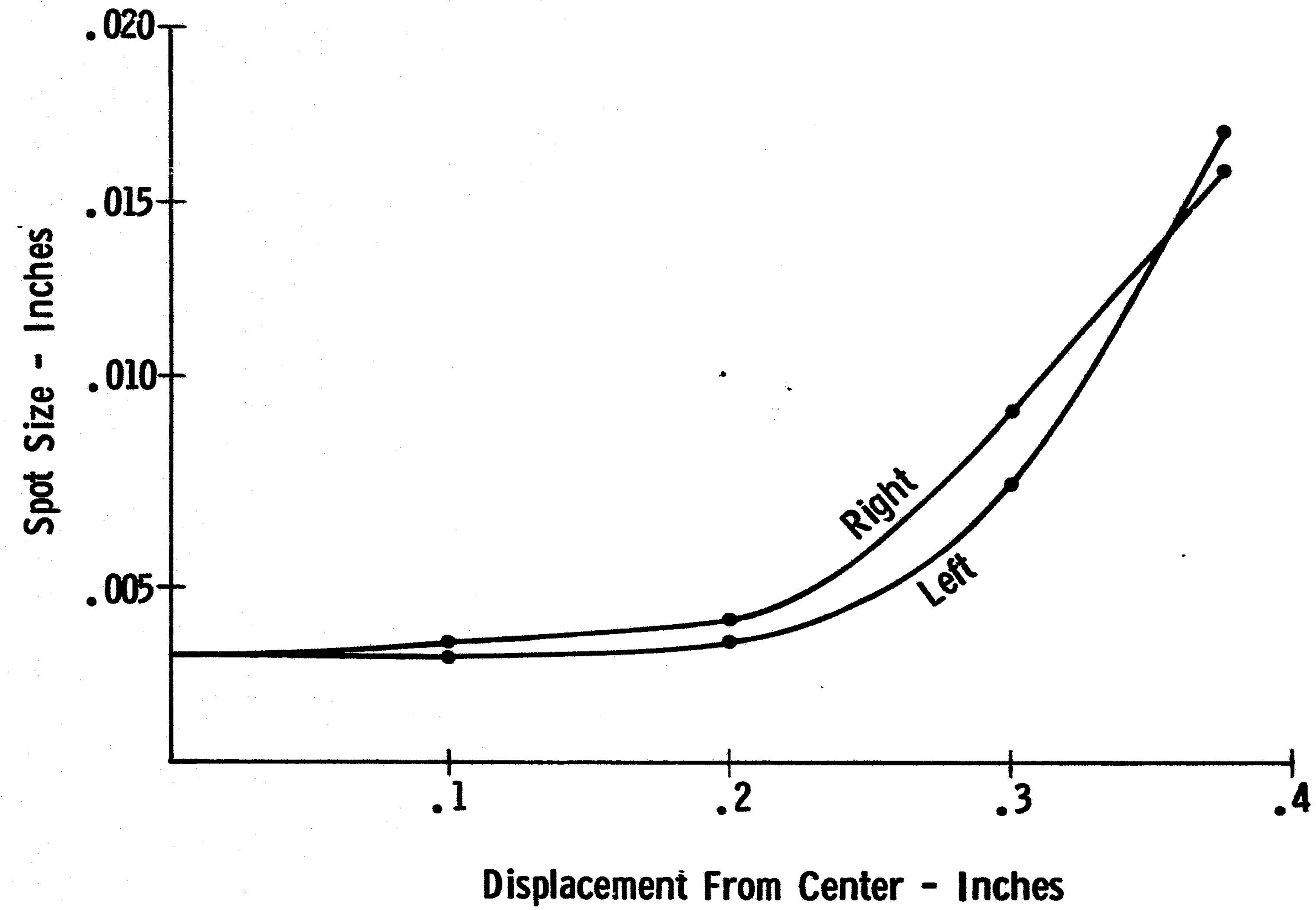
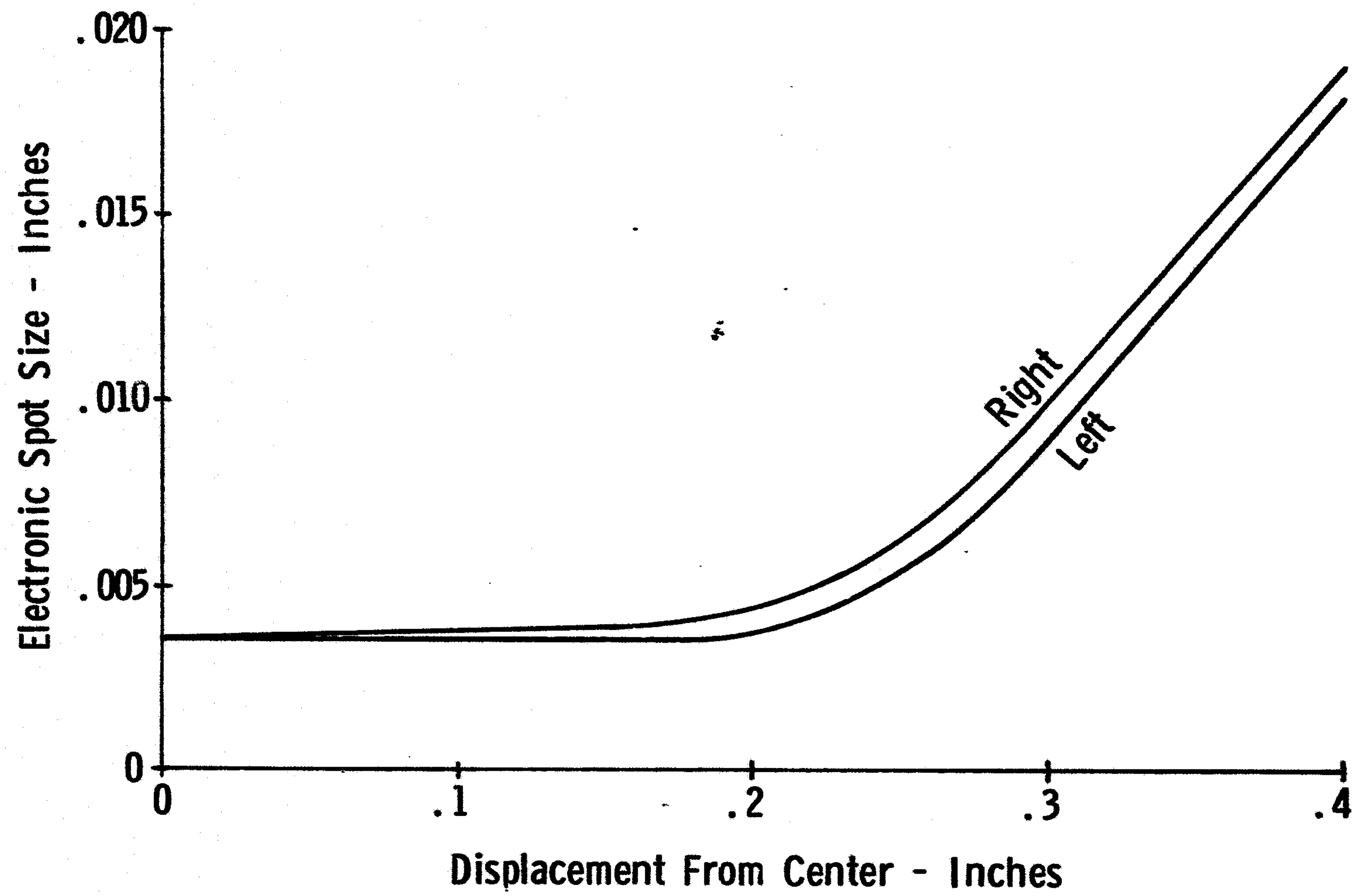


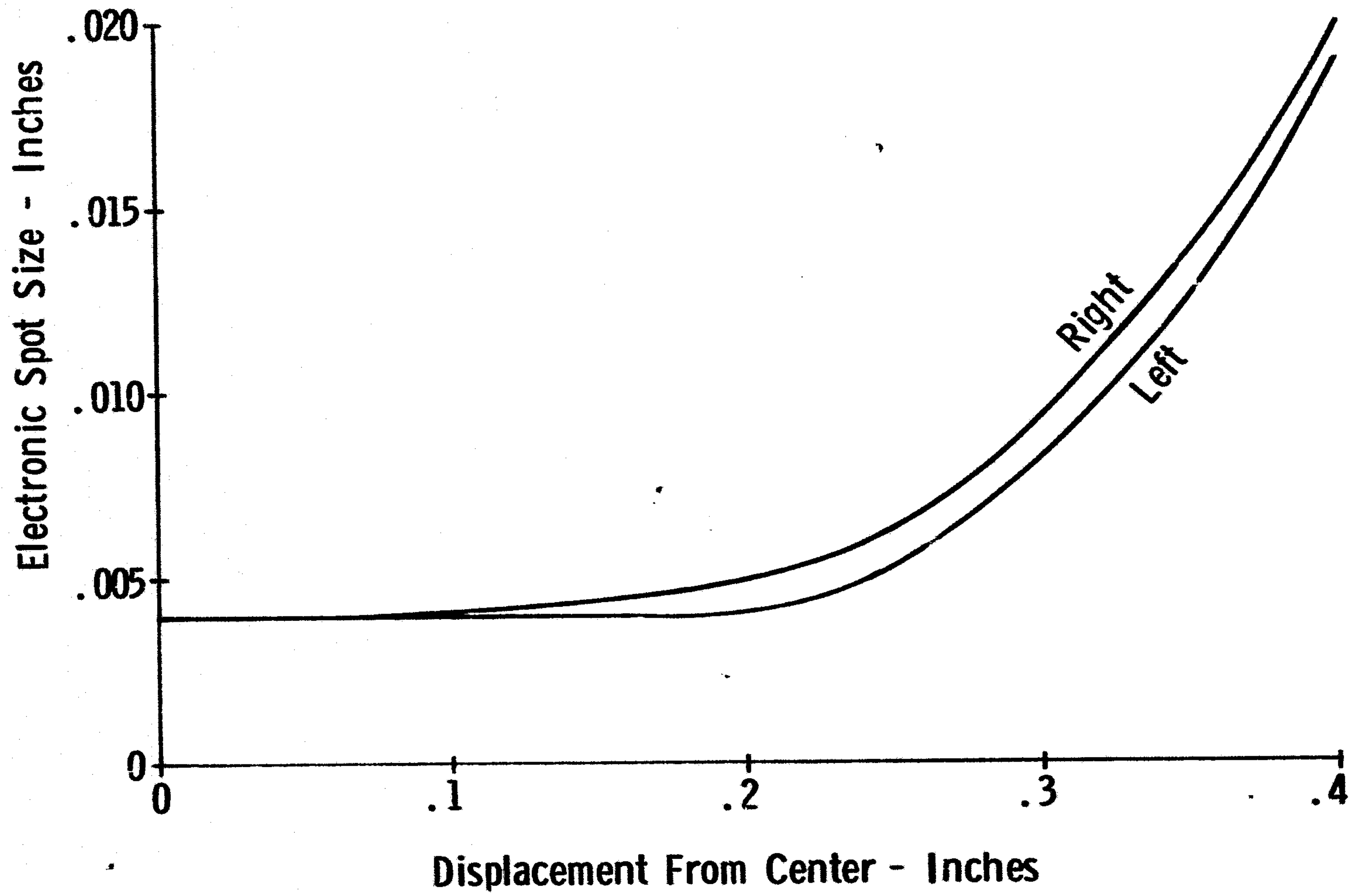
FIG. 1



ELECTRONIC SPOT SIZE
Tube No. M1280

FIG. 2

etr 292



ELECTRONIC SPOT SIZE
Tube No. M1390

etr 293

FIG. 3

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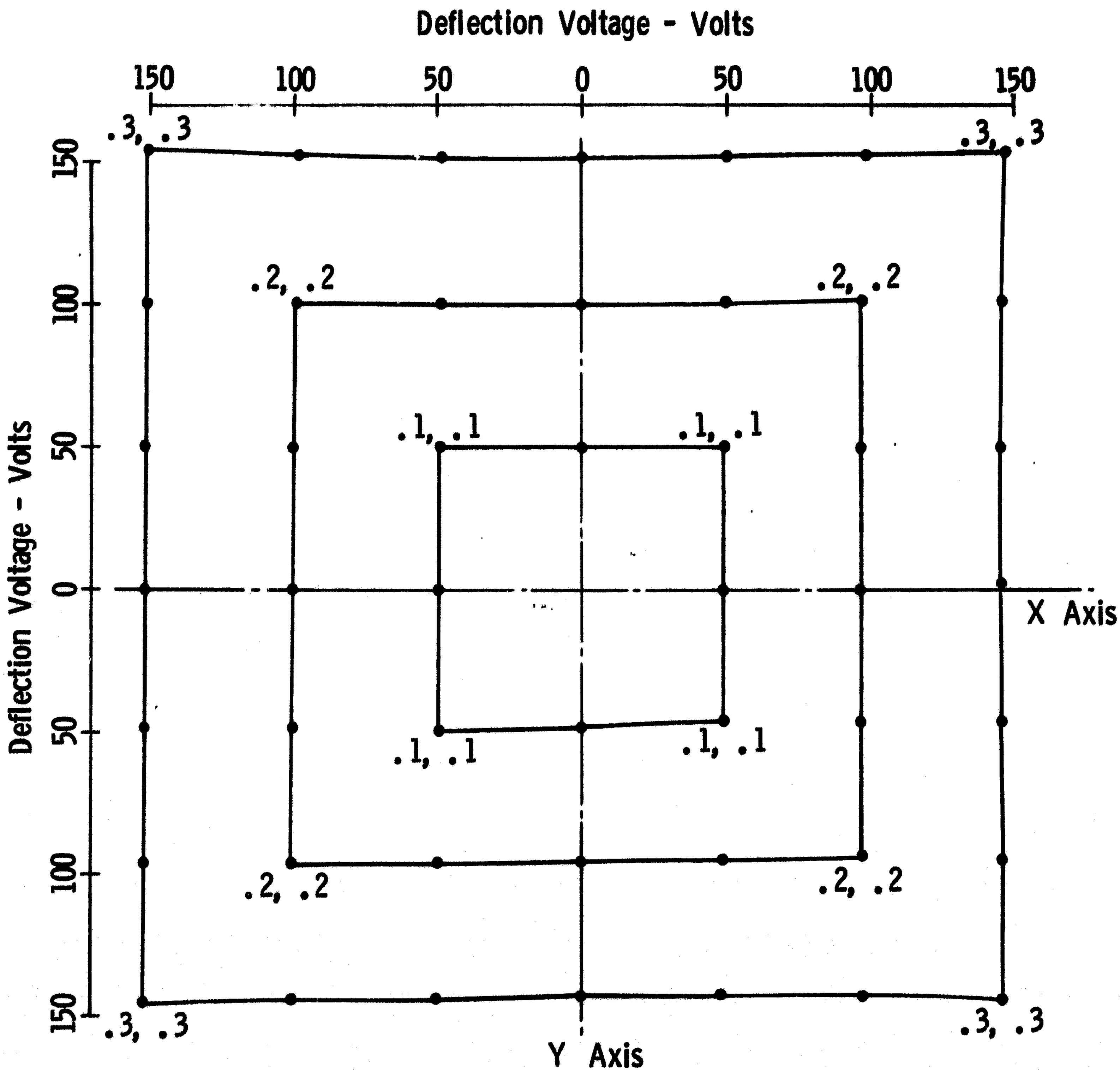
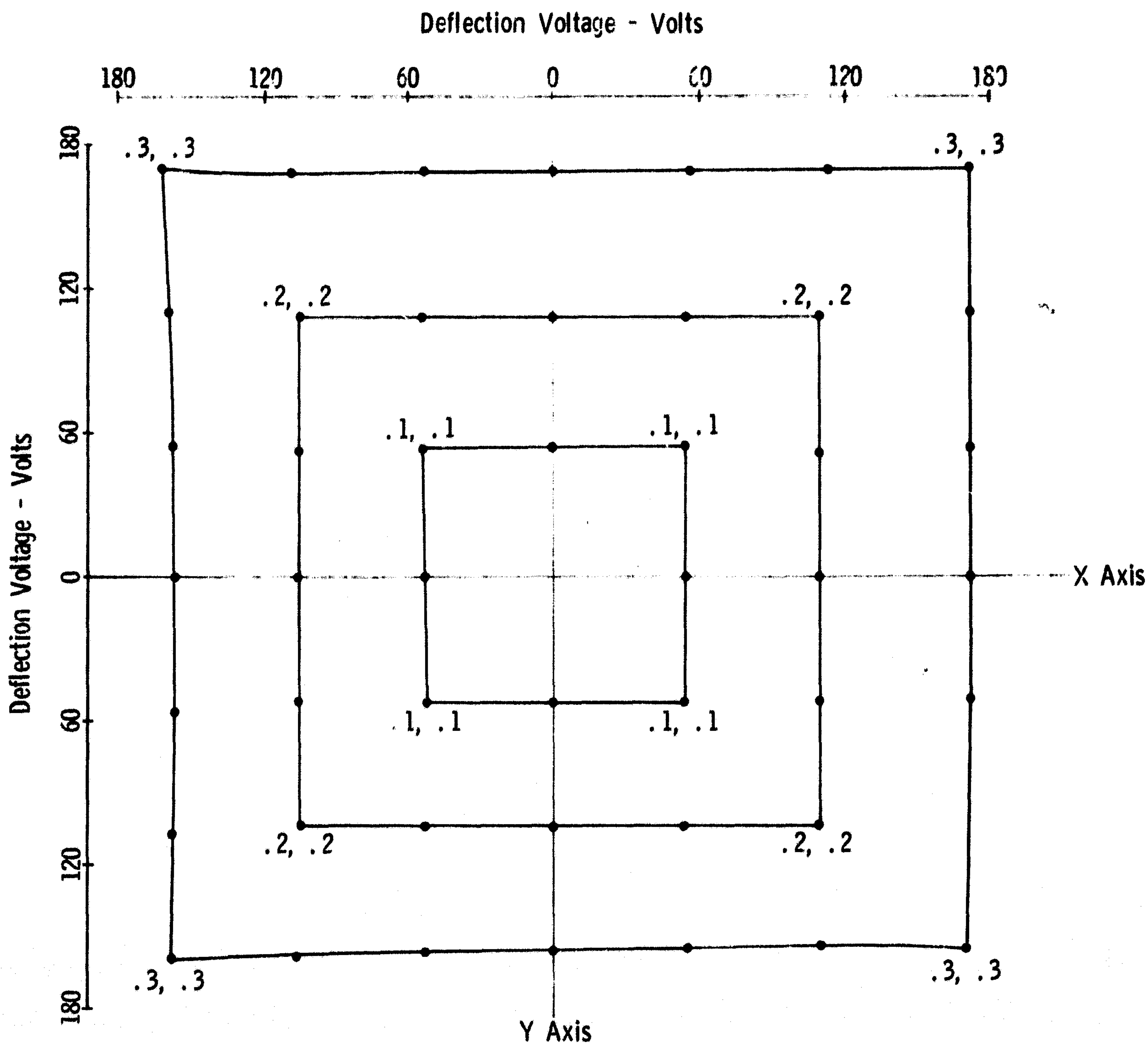
FIG. 4
EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1383





EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1389

etr 294

FIG. 5

DEFLECTION LINEARITY
Tube No. M1364

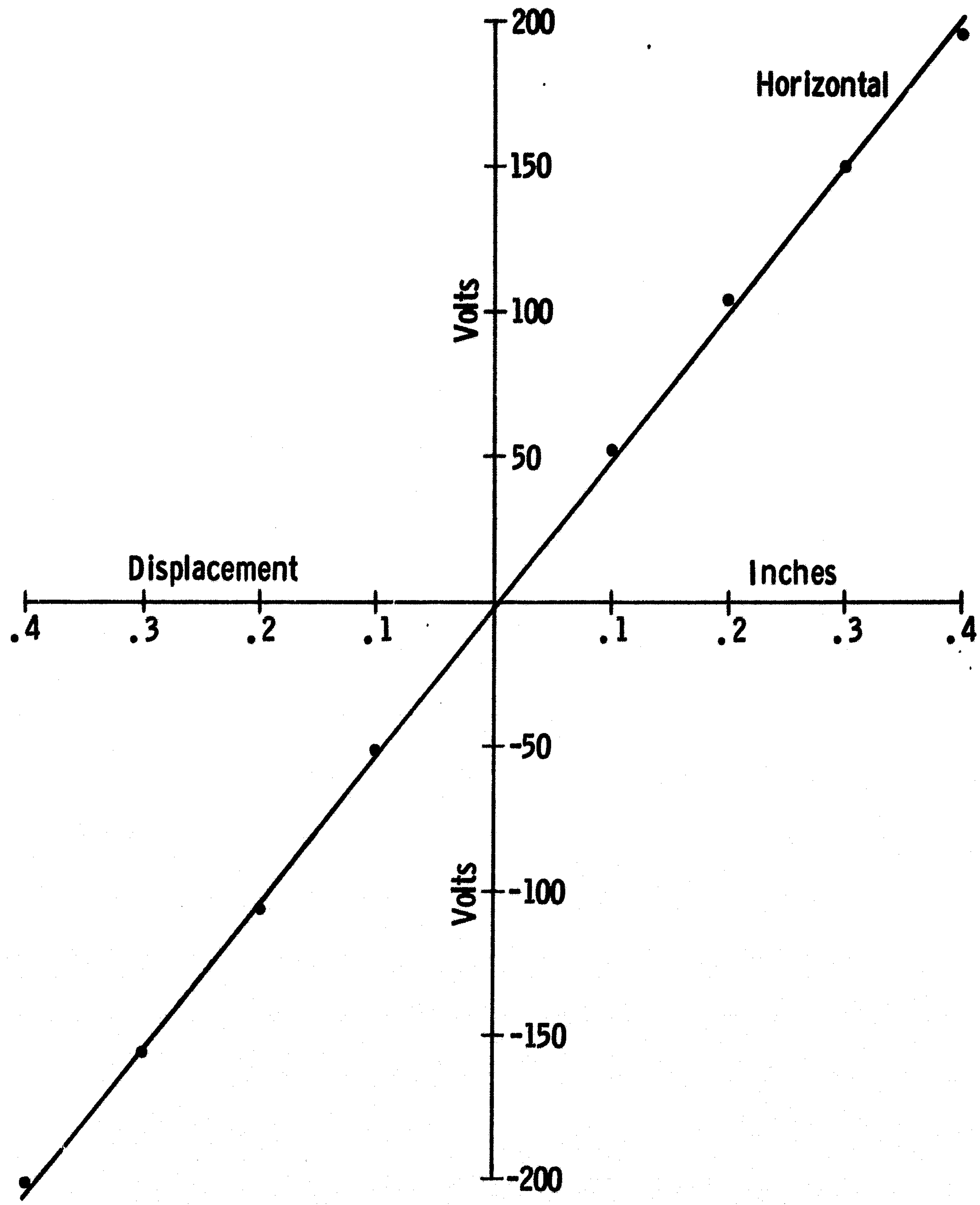


FIG. 6

DEFLECTION LINEARITY
Tube No. M1383

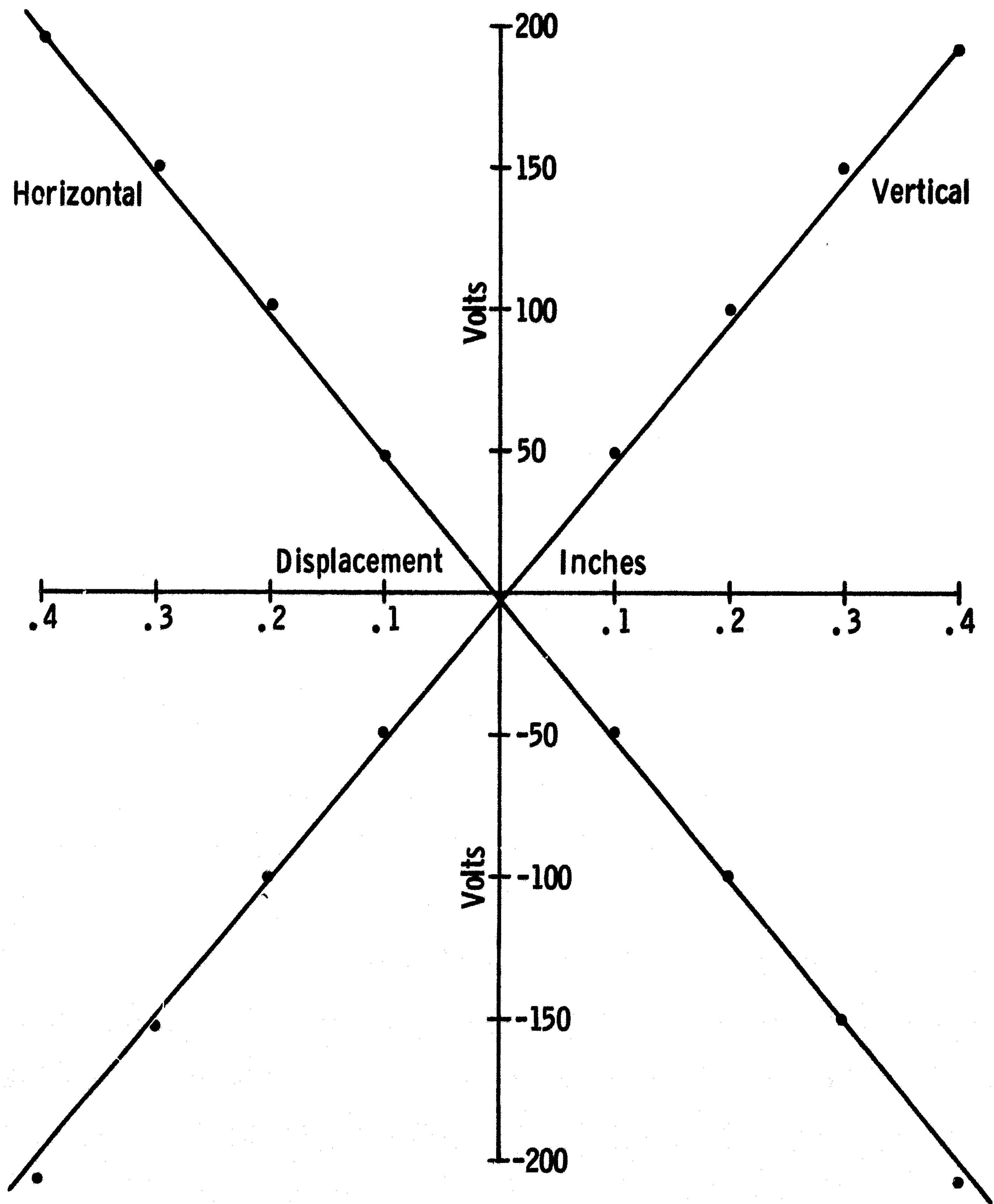
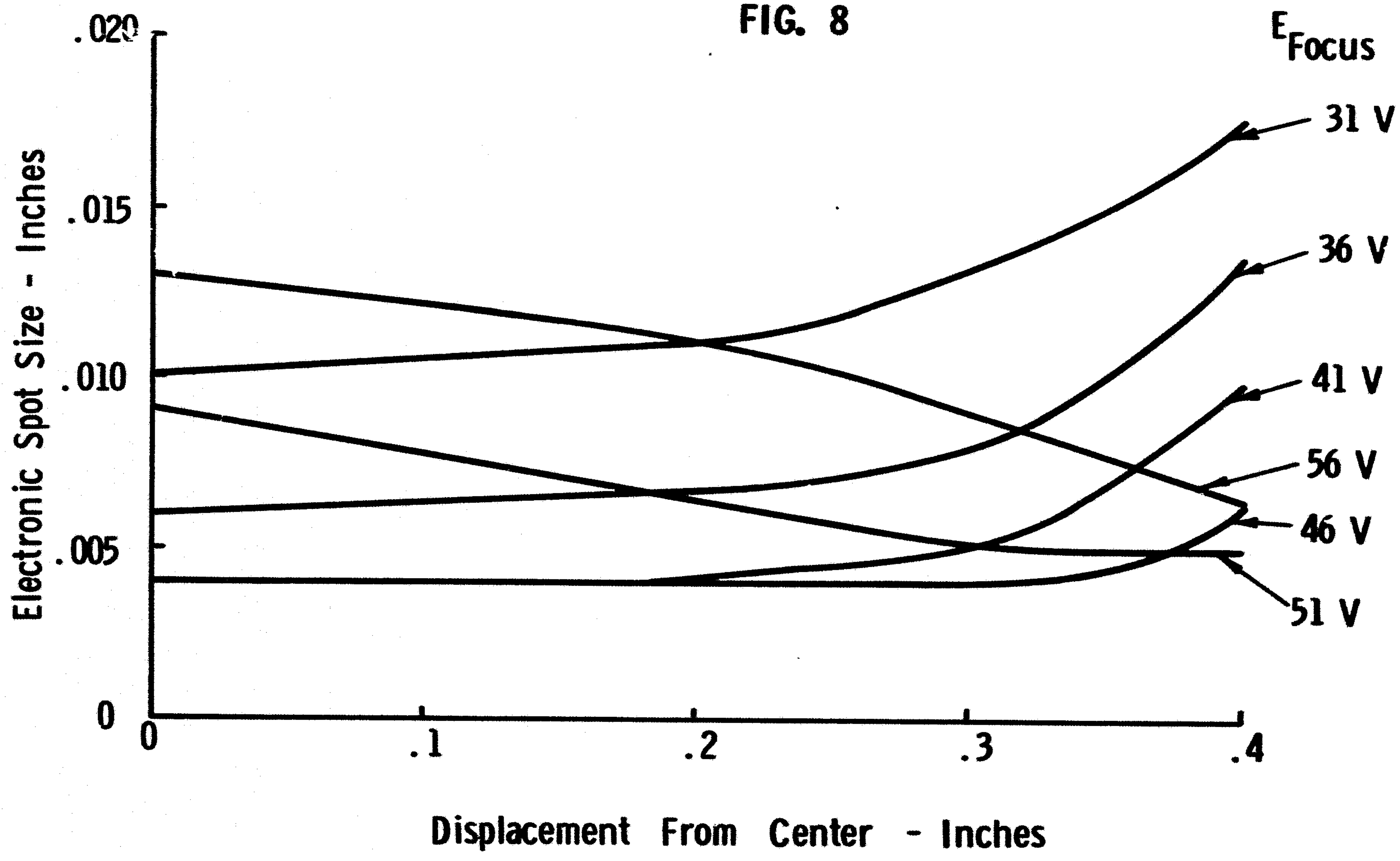


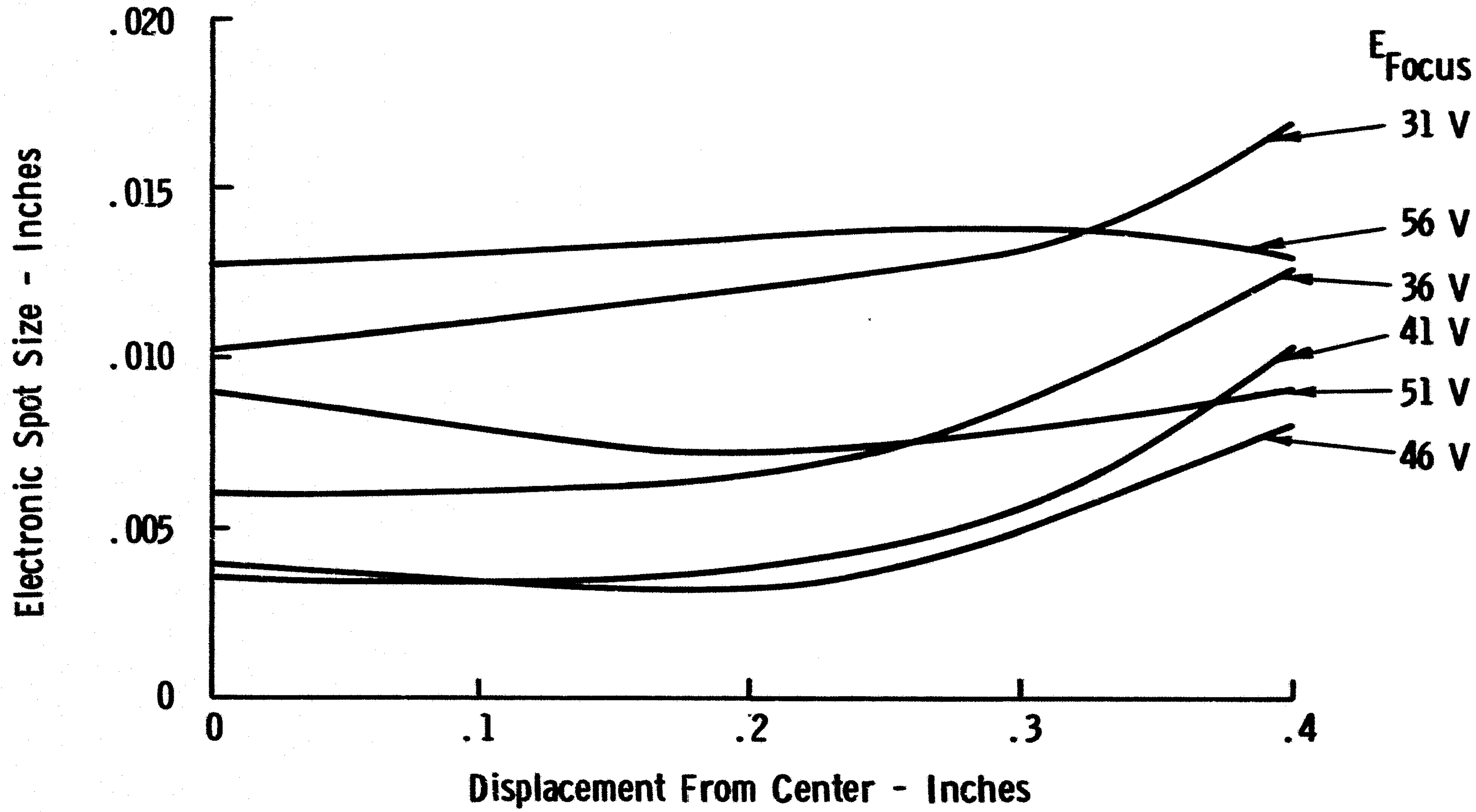
FIG. 7

FIG. 8

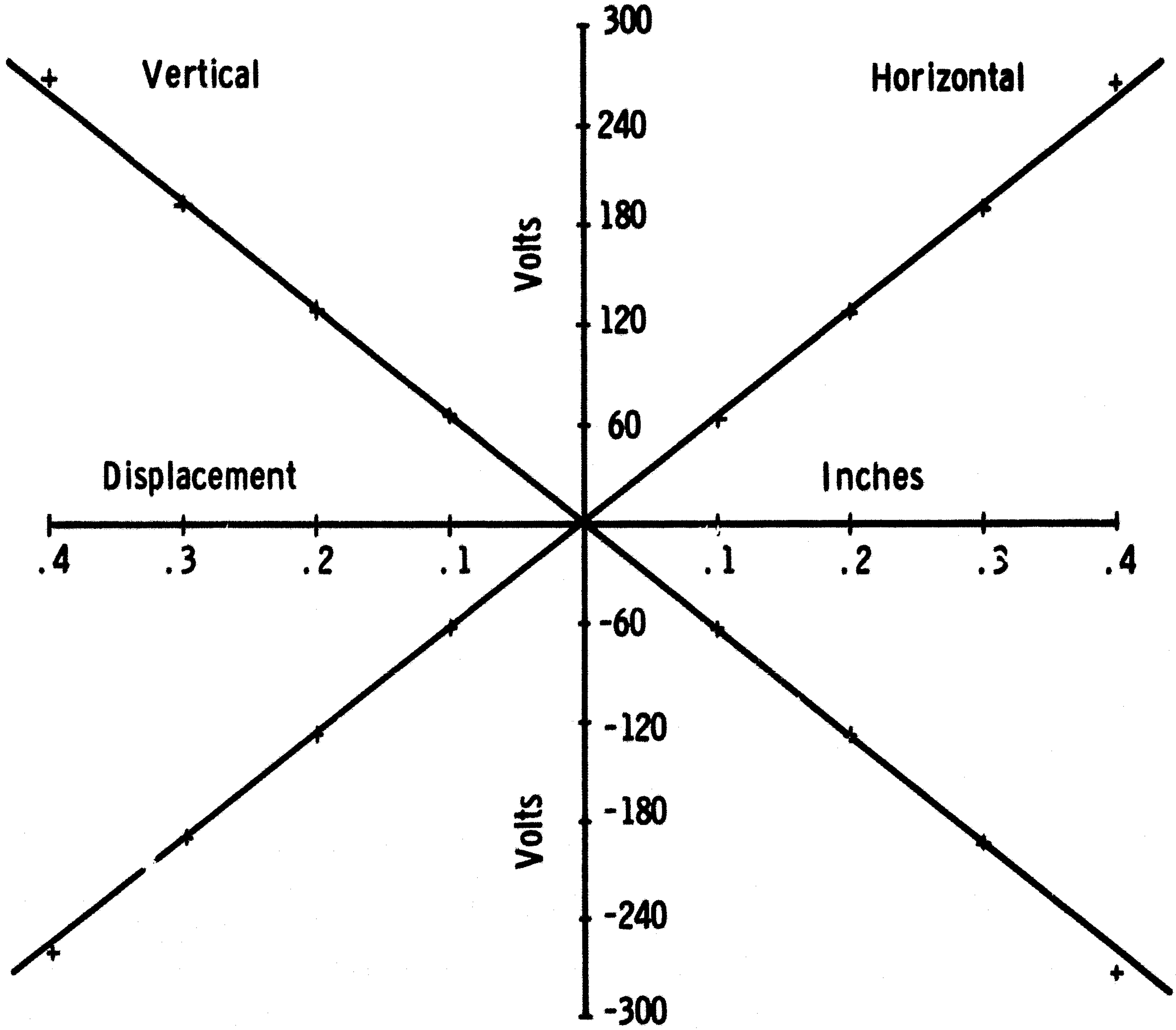


ELECTRONIC SPOT SIZE
No Deflection Voltage Employed
Tube No. M1409

FIG. 9

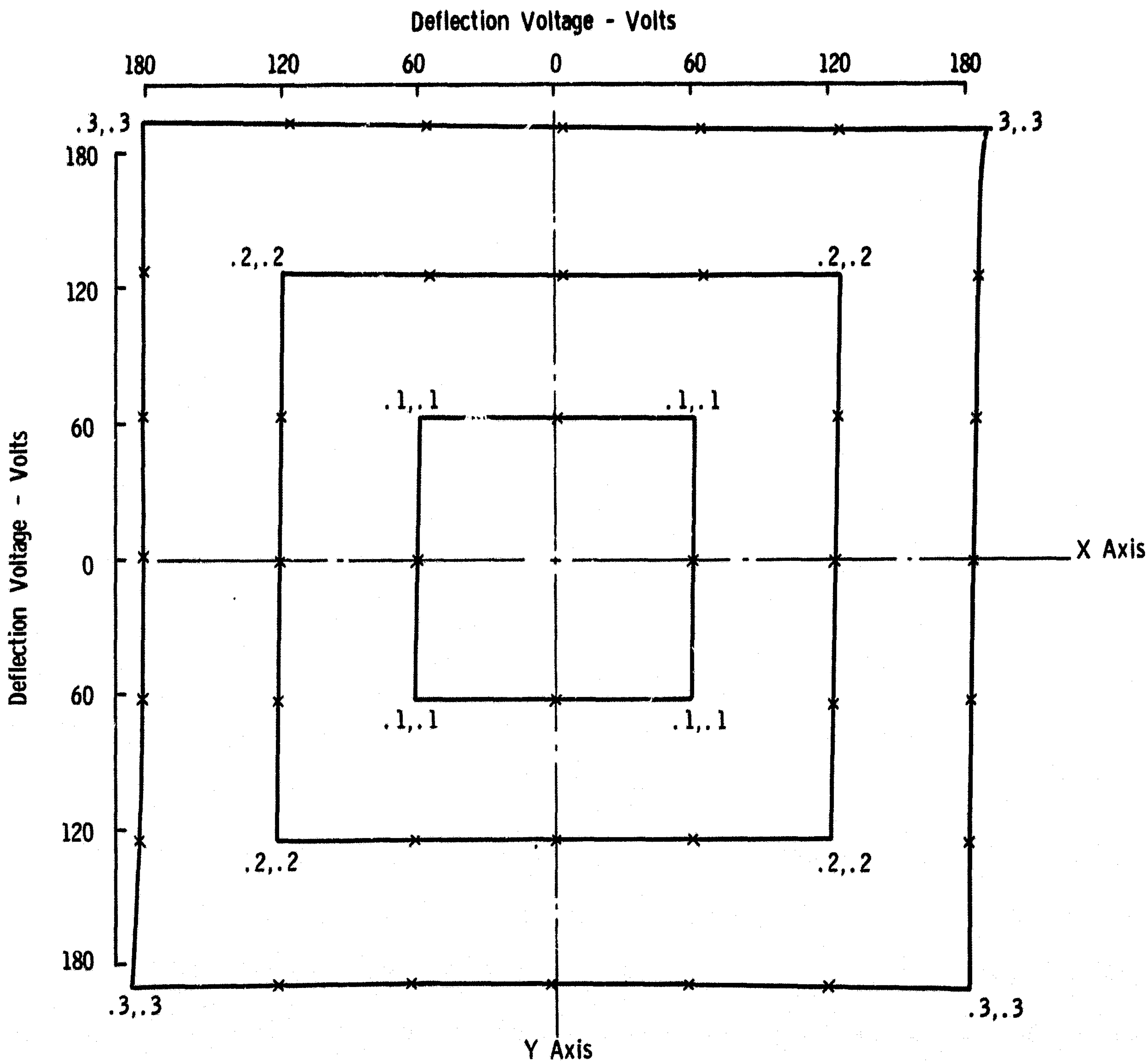


ELECTRONIC SPOT SIZE
Electrons Deflected Into The Center Of Tube
Tube No. M1409



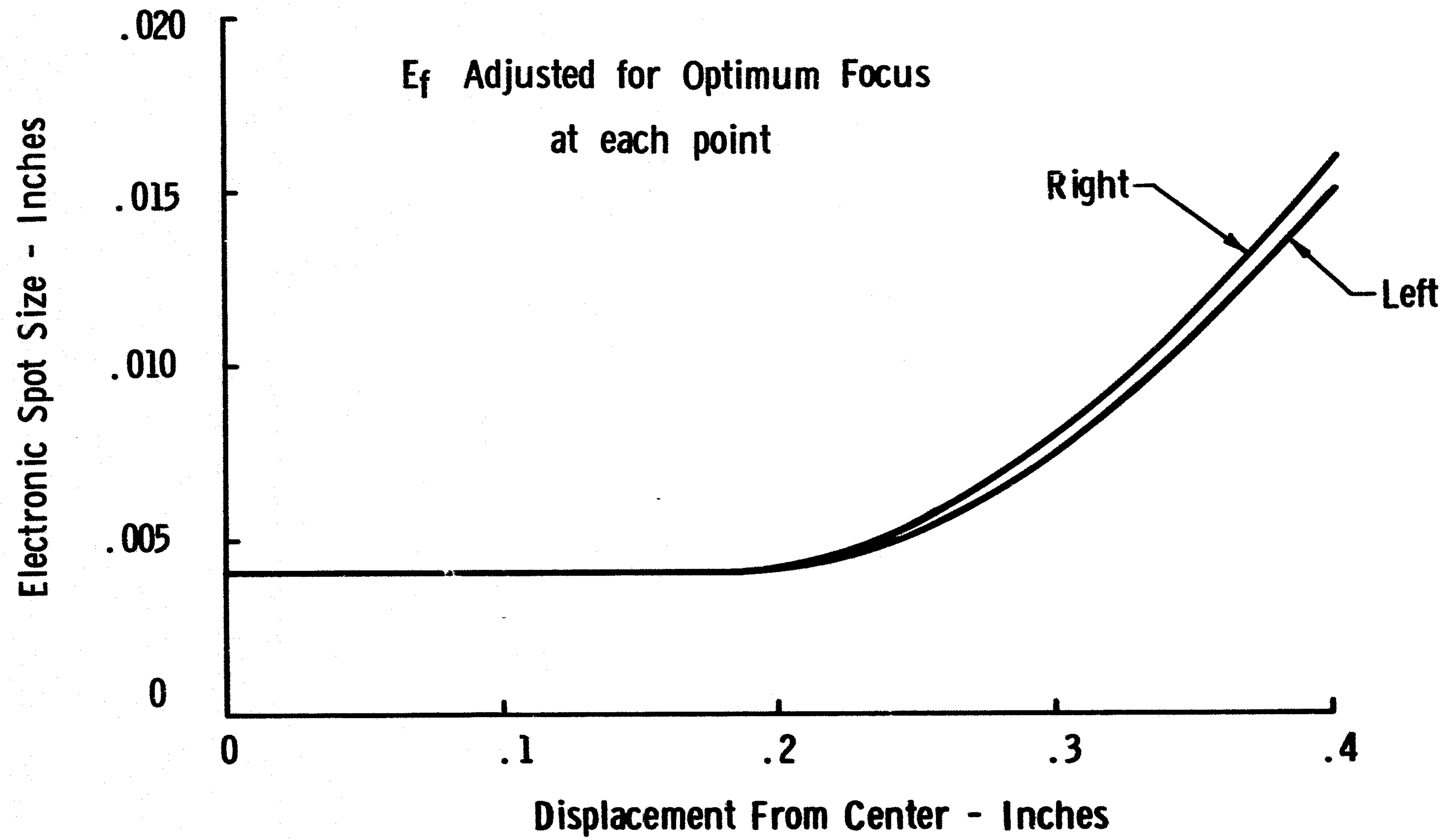
DEFLECTION LINEARITY
Tube No. M1414

FIG. 10



EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1414

FIG. 11



ELECTRONIC SPOT SIZE
Tube No. M1415

FIG. 12

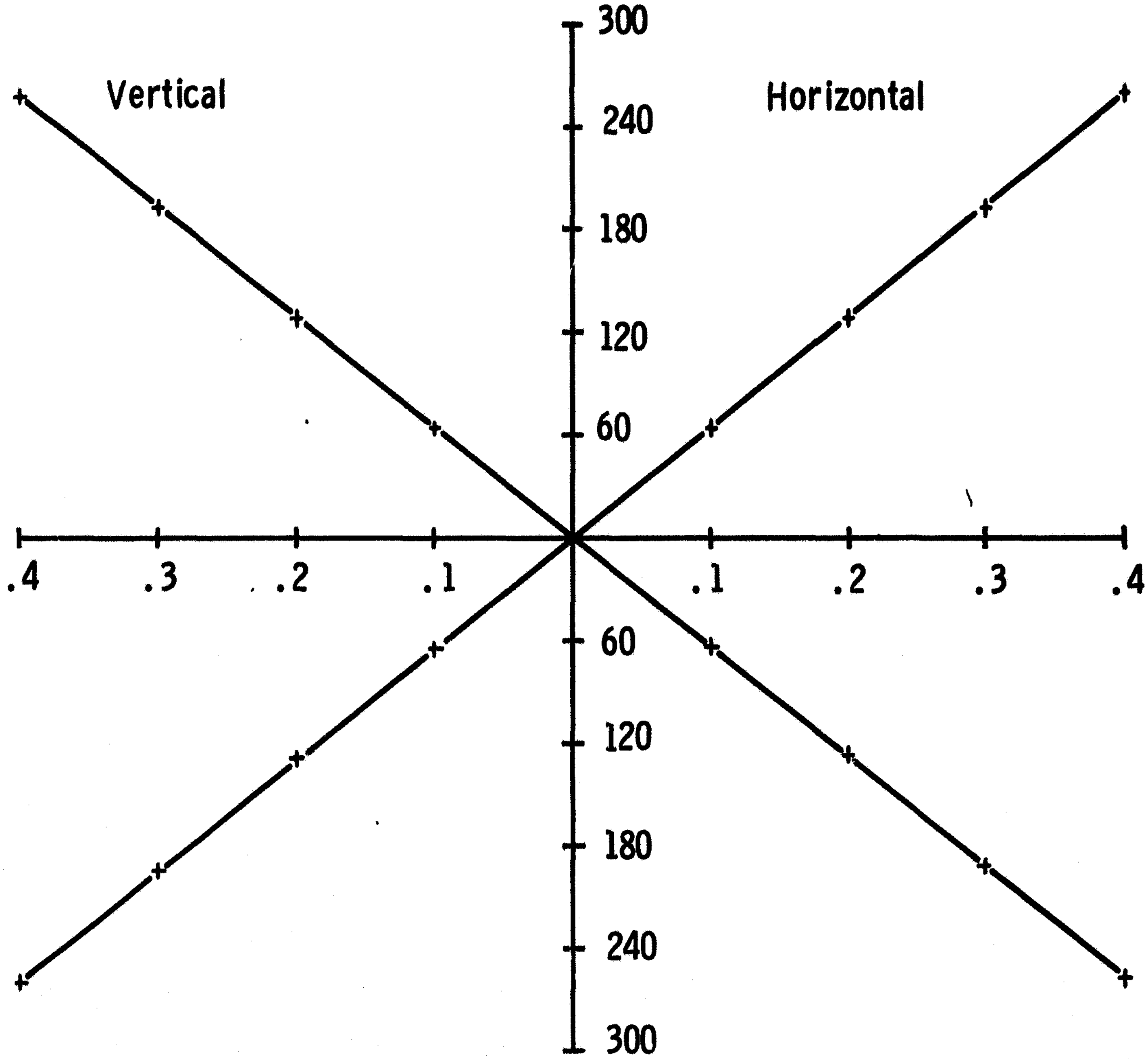
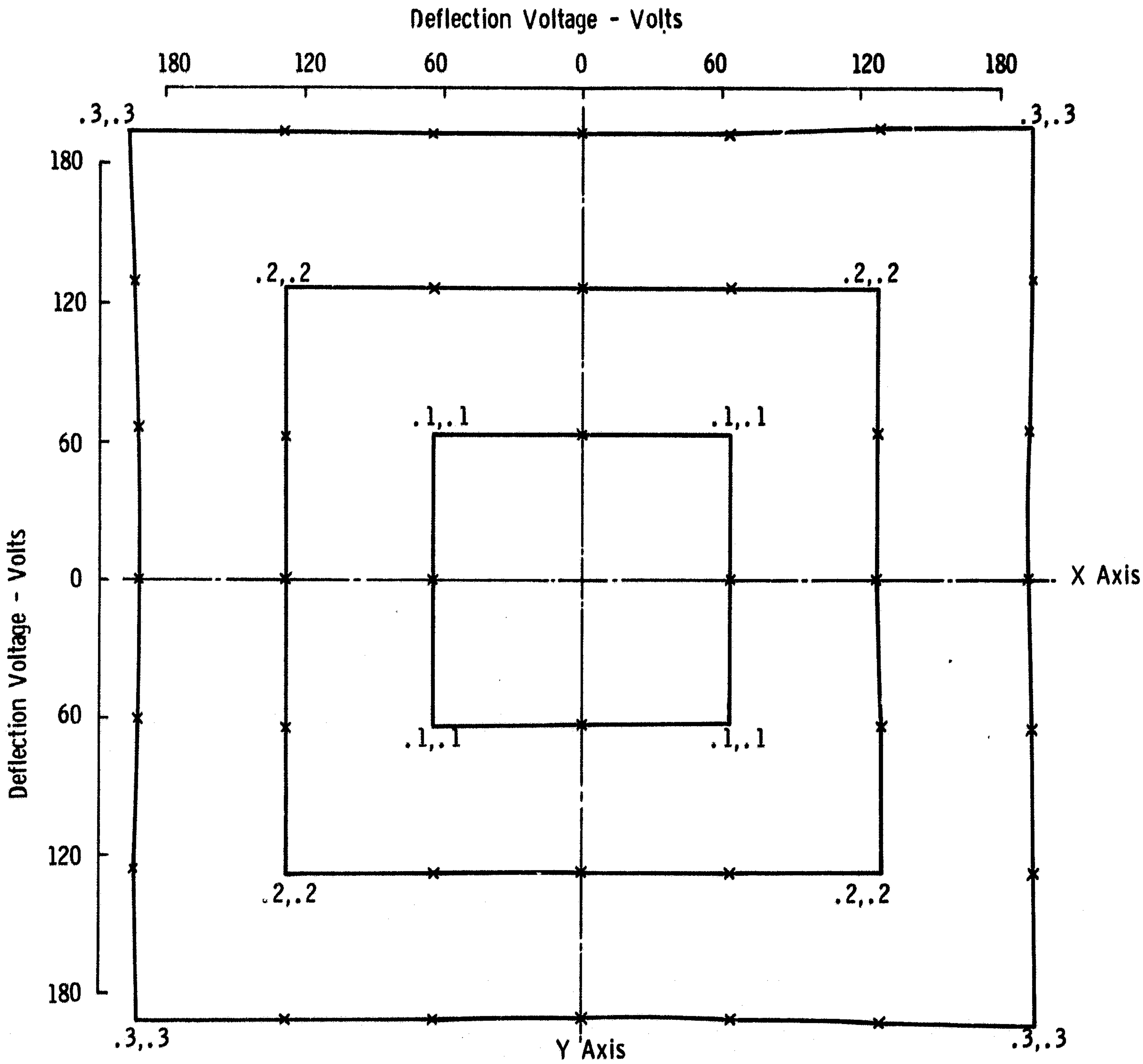


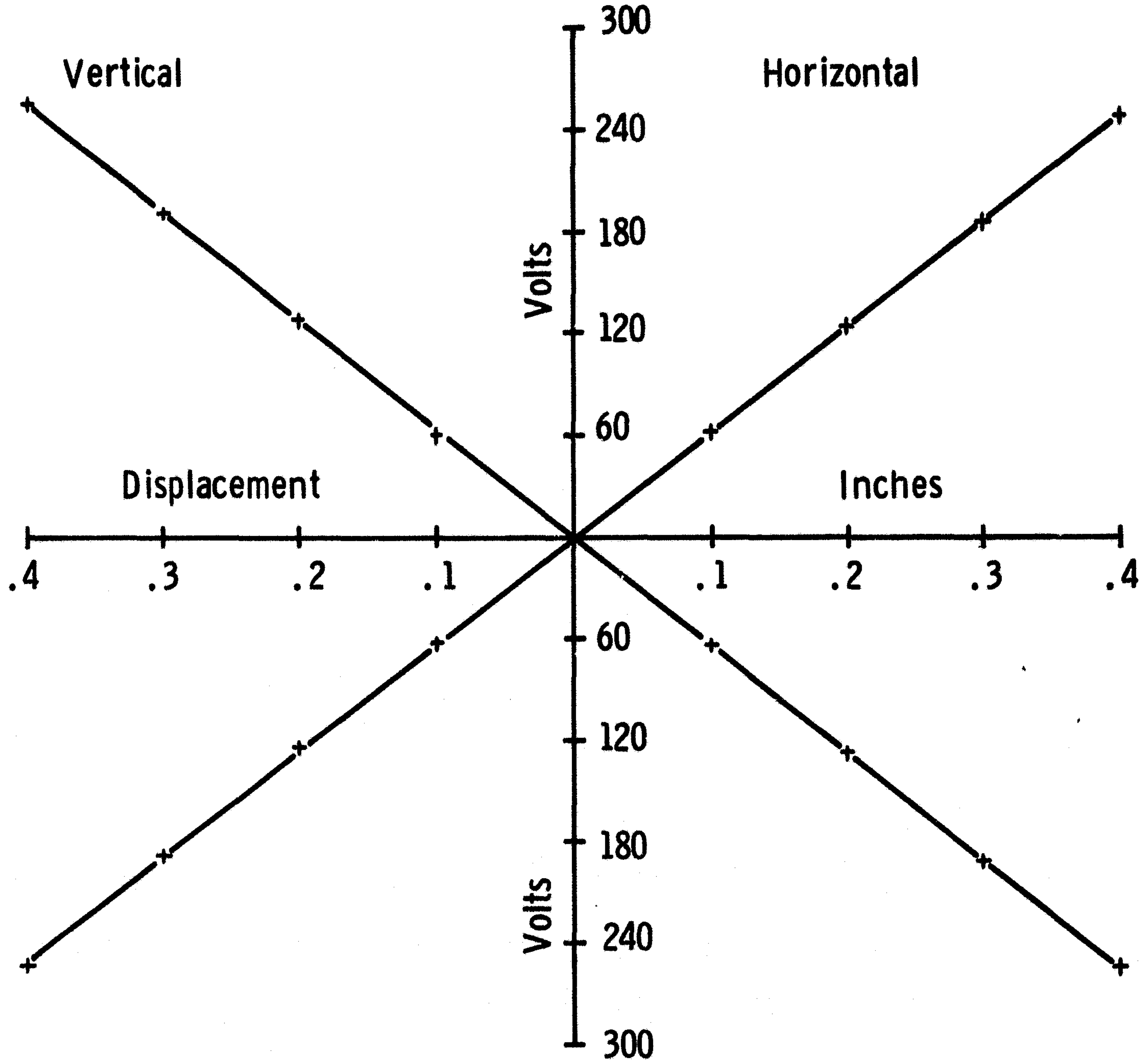
FIG. 1
DEFLECTION LINEARITY
Tube No. M1416

FIG. 13



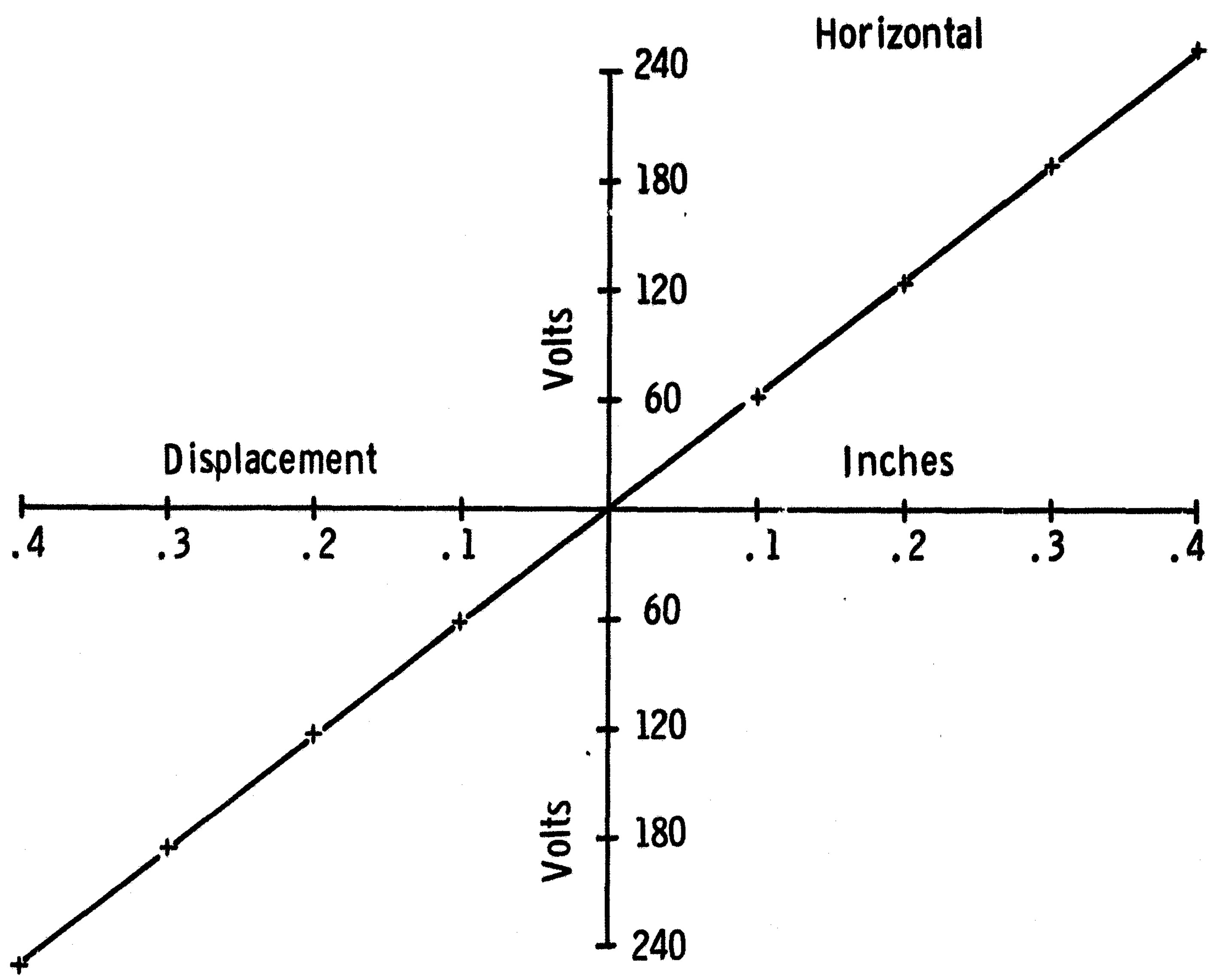
EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1416

FIG. 14



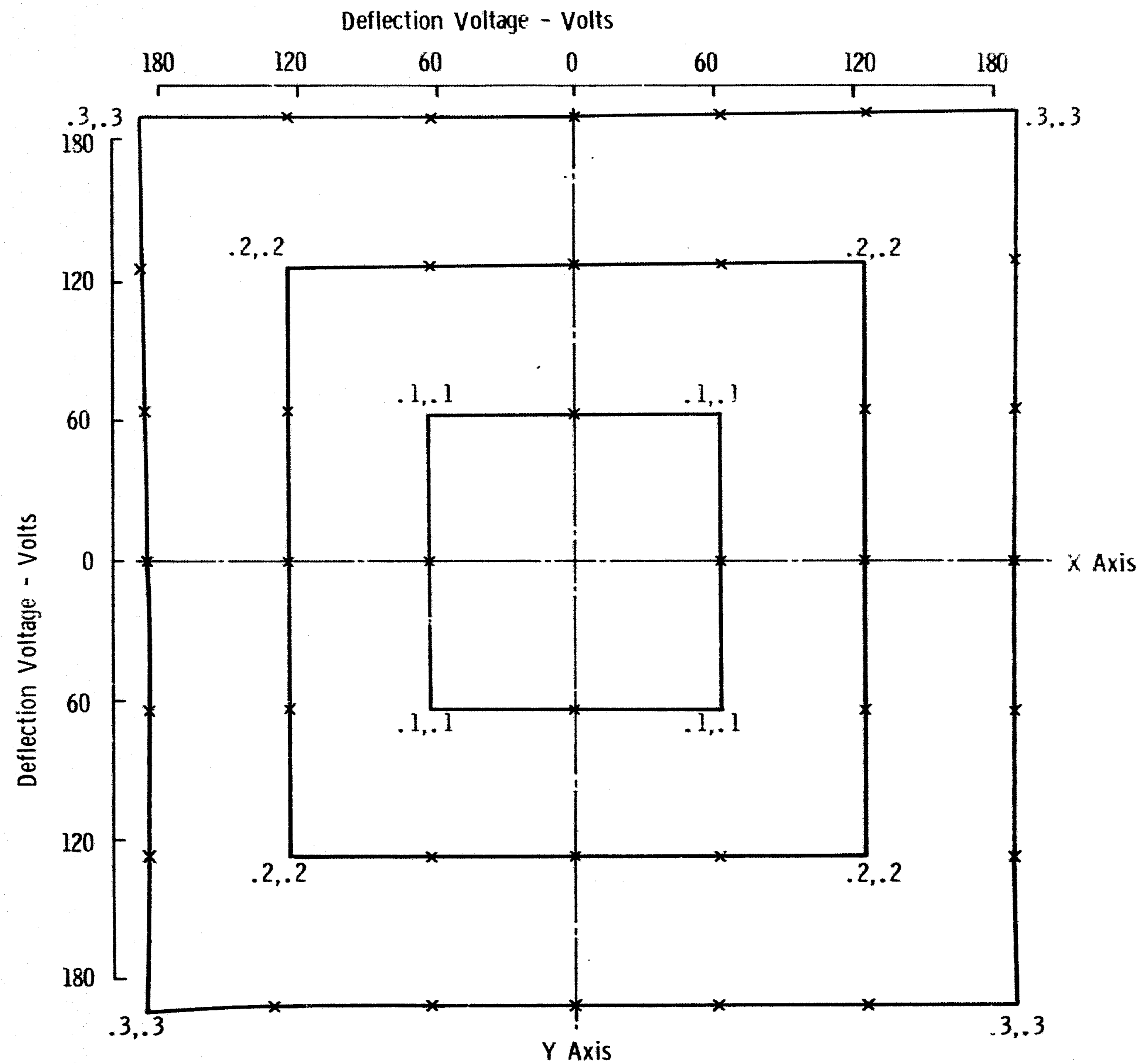
DEFLECTION LINEARITY
Tube No. M1421

FIG. 15



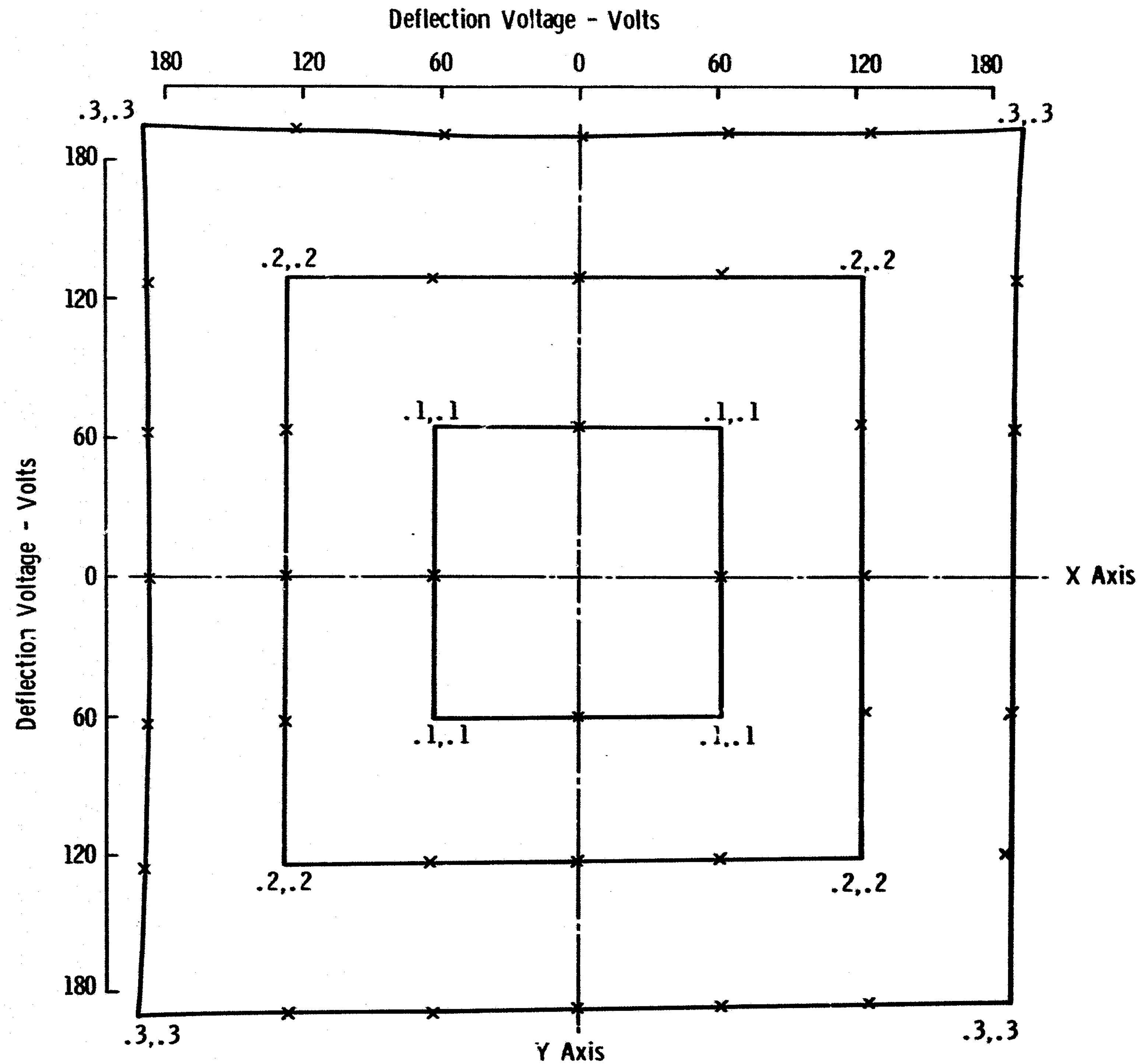
DEFLECTION LINEARITY
Tube No. M1422

FIG. 16



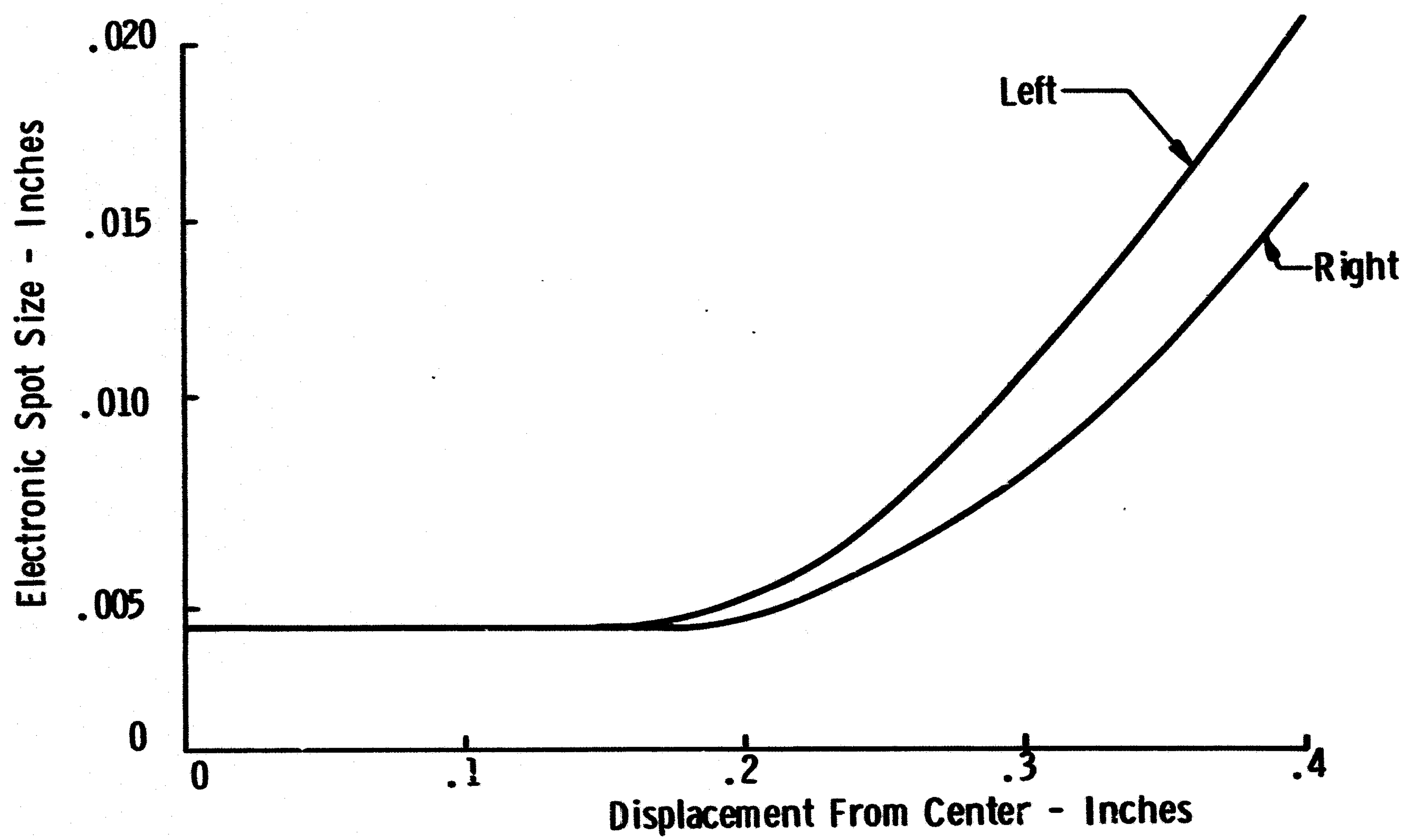
EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1421

FIG. 17



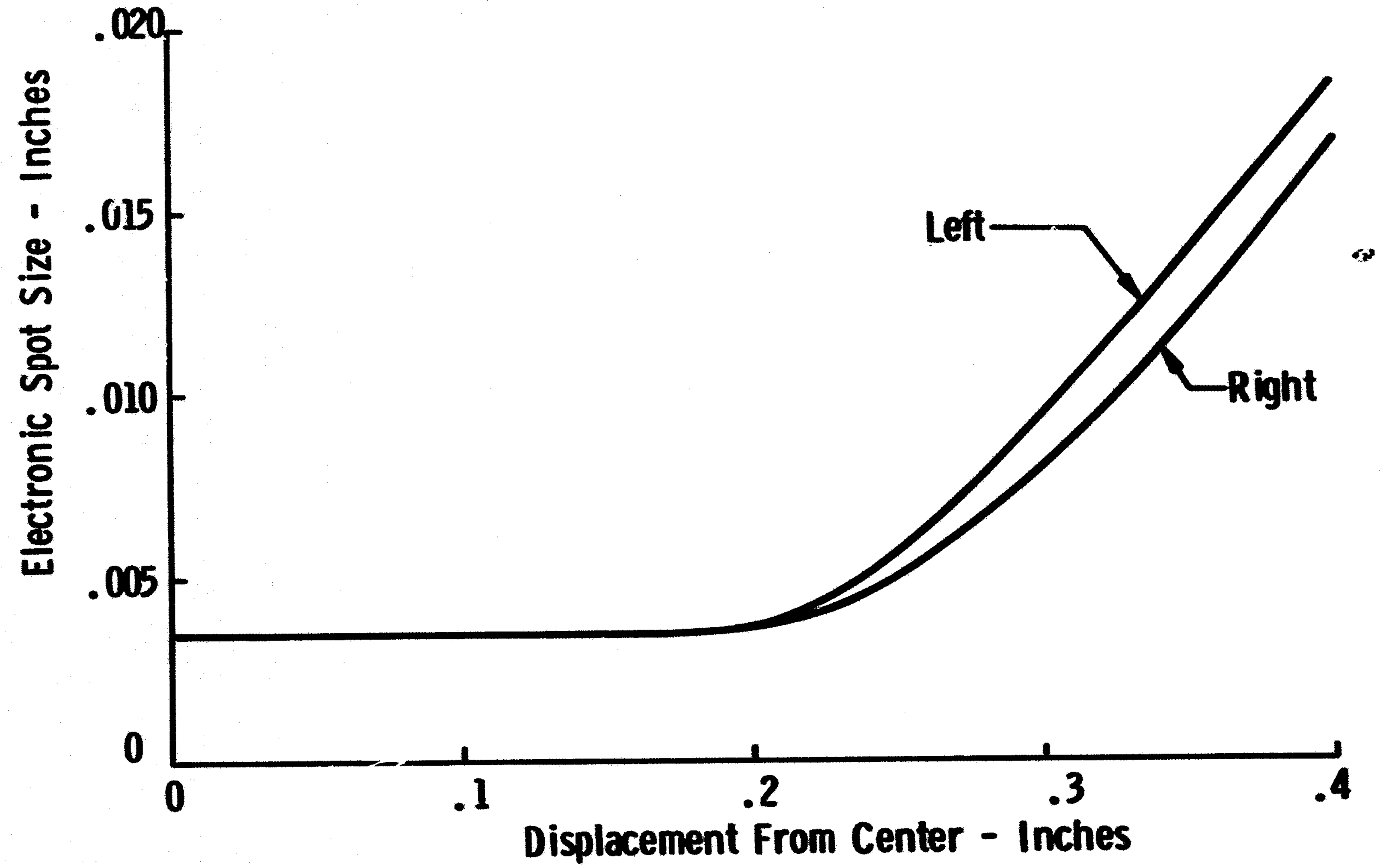
EQUI-POTENTIAL DEFLECTION CURVES
Tube No. M1422

FIG. 18



ELECTRONIC SPOT SIZE
Tube No. M1417

FIG. 19



ELECTRONIC SPOT SIZE
Tube No. M1422

FIG. 20

etr 605

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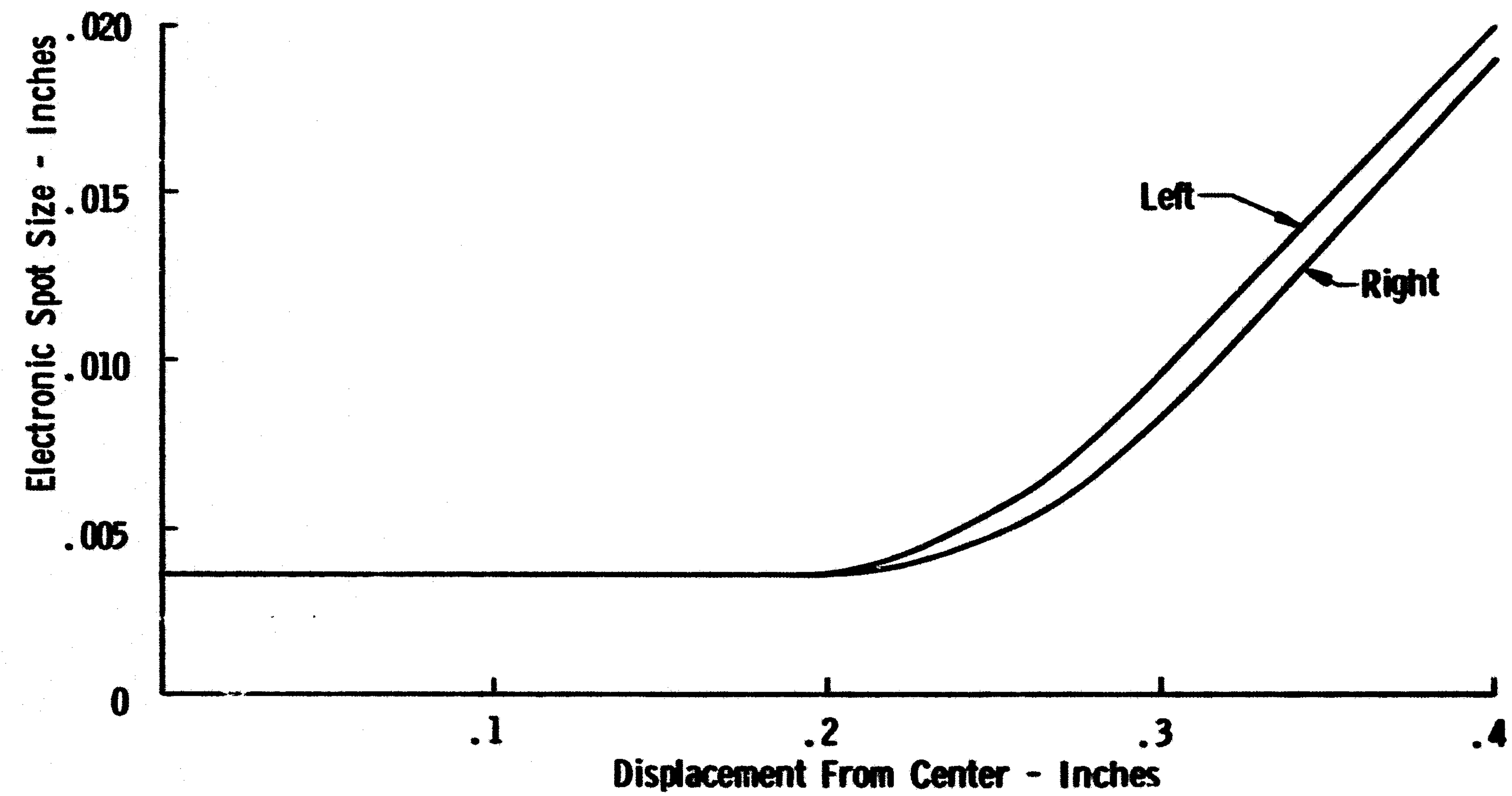
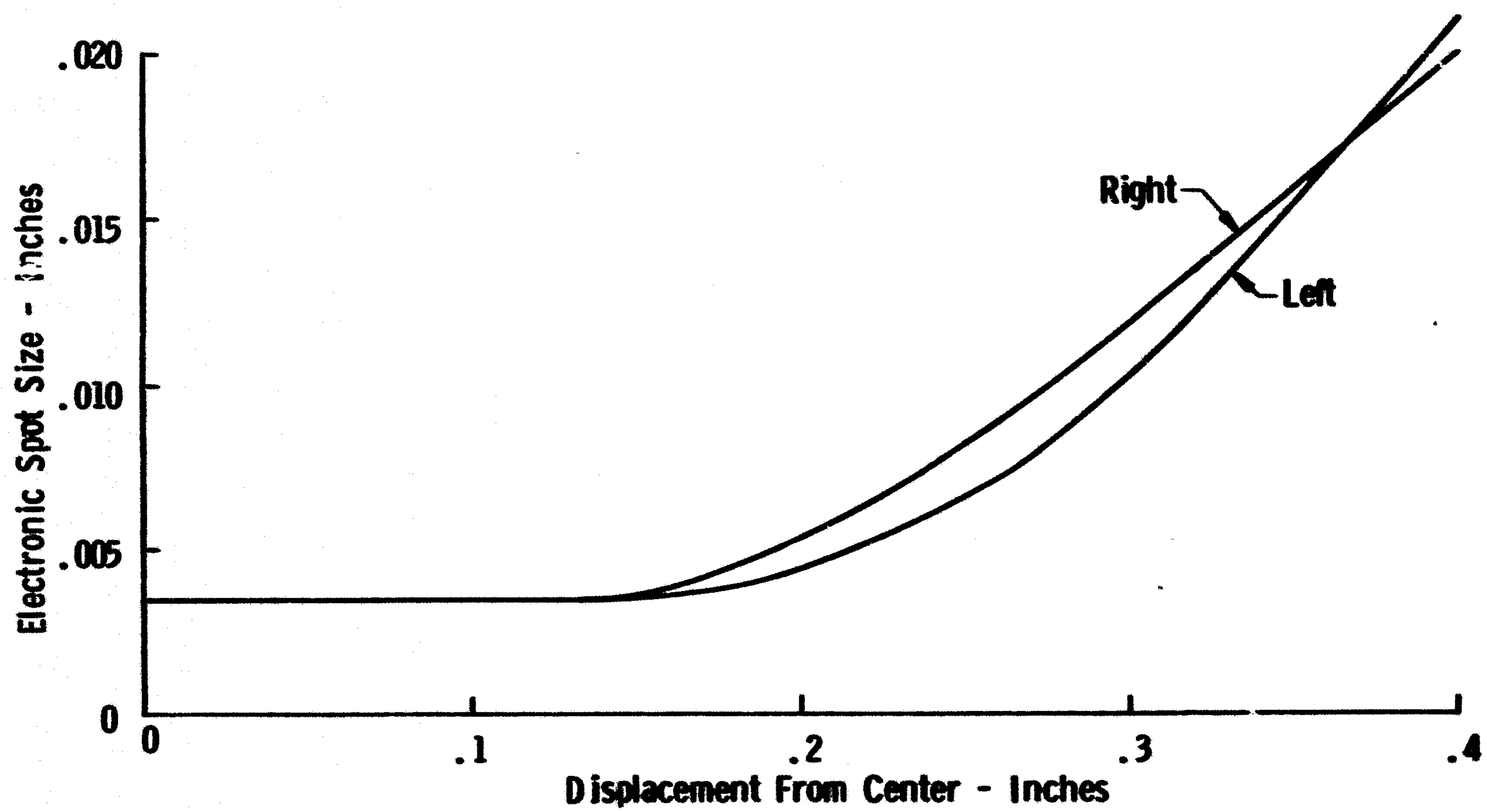


ELECTRONIC SPOT SIZE
Tube No. M1433

FIG. 21

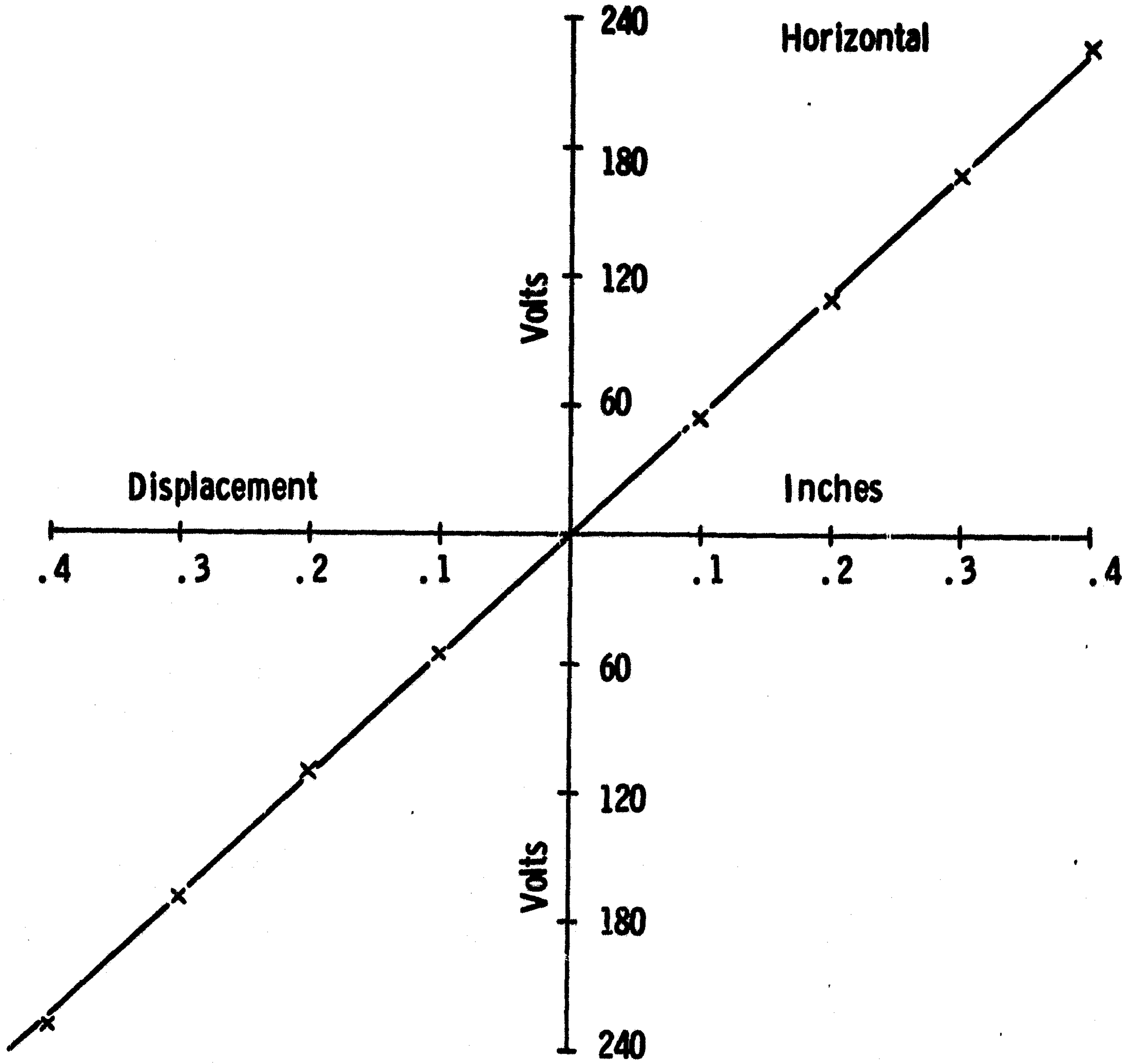
etr 643



ELECTRONIC SPOT SIZE
Tube No. M1423

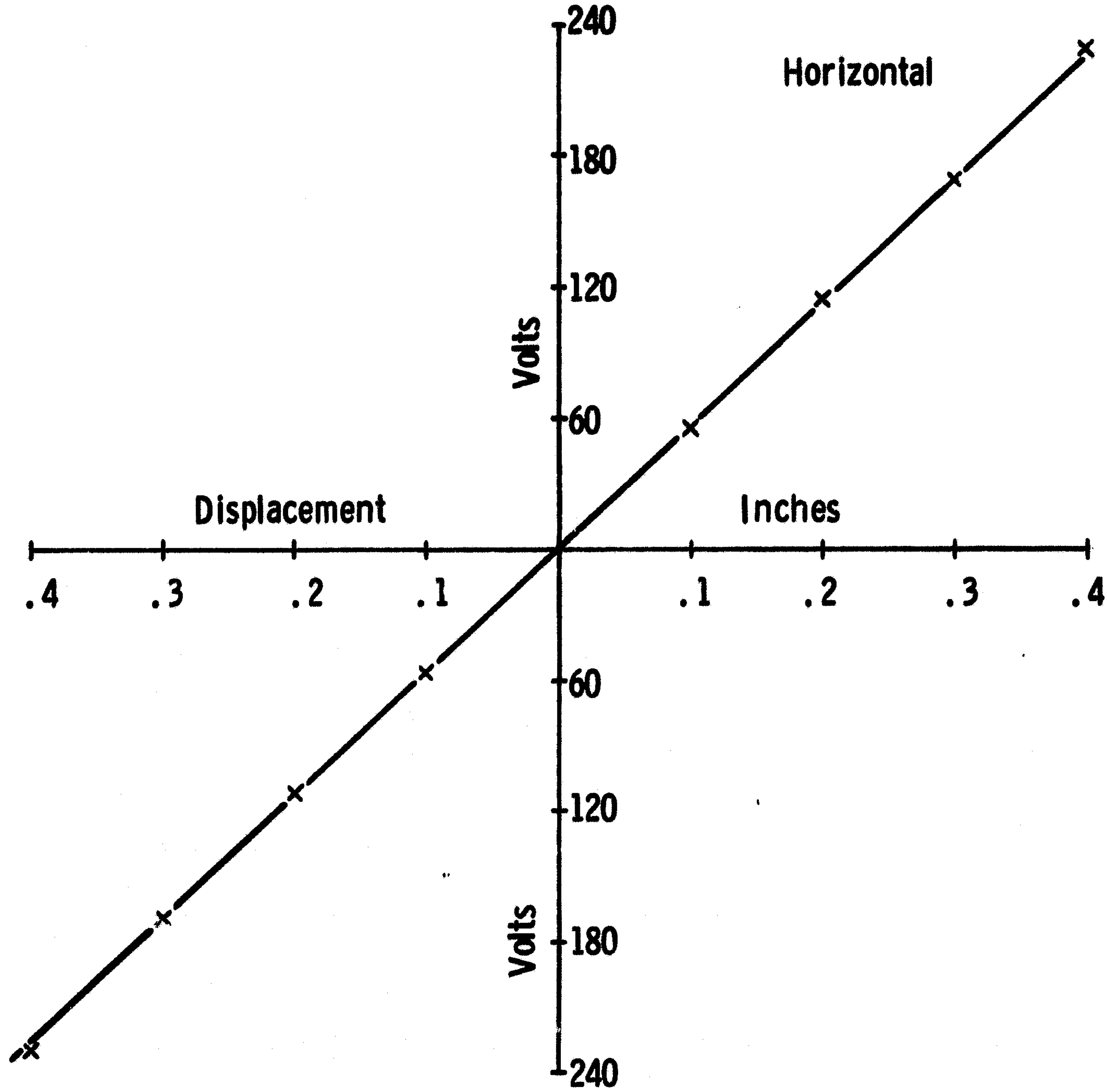
FIG. 22

etr 644



DEFLECTION LINEARITY
Tube No. M1423

FIG. 23



DEFLECTION LINEARITY
Tube No. M1433

FIG. 24

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Appendix I

PHASE I

PROGRESS REPORT

THE DEVELOPMENT OF HIGH RESOLUTION, HIGH STABILITY
STERILIZABLE IMAGE DISSECTOR TUBES

1. SUMMARY

This report covers the first phase of Contract No. 951477. During this phase the existing data on sterilized bi-alkali photomultipliers and image dissectors was reviewed and photocathode processing experiments were devised. The designs of experimental 2 1/4" diameter, 10 stage photomultipliers were completed and parts were ordered. Alkali generators were evaluated and improvements were made in their preparations.

Electron-optical experiments directed toward the improvements of resolution, were designed and the effect of the deflectron configuration on deflection sensitivity was determined. Estimates of electron trajectories were prepared for normally emitted electrons at distances of .450", .225" and .110" from the electrical center of the photocathode. A test specification and sterilization test flow plan were prepared.

2. TECHNICAL STATUS

2.1 Bi-alkali Photocathode Development

2.1.1 Process and Data Review

The data generated under JPL Contract No. 950784 was reviewed. From these it was determined that the developed activation schedules did not produce photocathodes with good stability. The sensitivity and the uniformity of response of the photocathodes deteriorated seriously in the 135°C, 92 hour thermal cycling. Comparisons of overall sensitivity and the uniformity of the photocathode indicates that the poor uniformity was due to localized reactions between the substrate and the photocathode and not the activation procedure itself.

The exceptional stability of the photosurface of tube M1319 in which the cathode substrate was subjected to prior treatment tends to confirm this. The treatment of substrate in tube M1319 consisted of predeposition of antimony and the alkali elements and subsequent bake at high temperature to remove the predeposited layer from the substrate. The tube was then reprocessed using the standard activation schedule. The photocathode sensitivity and response uniformity of tube M1319 was not adversely affected by thermal cycling.

2.1.2 Proposed Photocathode Processing Experiments

The proposed processing experiments based on the activation schedule of tube M1319 consist of the following:

A. Exact duplication of the schedule used with tube M1319.

B. Variations in bake off temperature.

C. Variations in duration of bake off.

D. Variations in the amount and combinations of the predeposited photocathode elements.

E. Variations in duration of initial bake prior to predeposition of the alkali elements.

2.1.3 Experimental Photomultipliers

The bi-alkali photocathode development work will be conducted using a modified 2 1/4" diameter, 10 stage photomultiplier. All designs of the photomultiplier were completed and orders were placed with the vendors.

The materials incorporated in the tube are the same as those of the image dissector. The envelope has a 0122 glass faceplate, frit sealed to a Driver-Harris 152 alloy ring which is in turn argon arc welded to a Kovar ring. The geometry of this is basically the same as that of the dissectors front end. Therefore, precisely identical cleaning and processing procedures will be possible. This approach will ensure that the results obtained with the photomultiplier will indicate what may be expected in later dissector fabrication.

2.1.4 Alkali Generators

In preparation for bi-alkali photocathode experiments, improvements were made in alkali generator fabrication. The methods of alkali powder preparation were revised and improved to assure minimum variations in the behaviour of generators during photocathode formation.

Special dry boxes were introduced to minimize the exposure of alkali powders to the atmosphere thus lessening the possibility of contamination.

A new methode for vacuum bake and vacuum storage of powders was devised; in which small amounts of powder are baked and stored in sealed glass capsules. Bi-alkali cathodes have been made to determine the effect of fine versus coarse alkali powders on photocathode sensitivity and rate of formation.

2.2 Proposed Electron Optical Experiments

The results of measurements performed under JPL Contract No. 950784 indicated that the rapid increase of the electronic spot size at points greater than 0.3 inches from the tube axis was partially due to distortion of the electron beam originating at the peripheral areas of the photocathode. Since it is suspected that the electron beam may be affected by the fringe fields of the deflection plates at the apex of the deflectron, a deflectron of increased diameter will be used in the initial experiment. A pincushion corrected, large diameter deflectron will be used in subsequent experiments.

The effect on resolution of a modified electric field, near the photocathode, will be investigated by varying the spacing between the photocathode and focus electrode by ± .050".

The effect on resolution of a modified electric field, near the apex of the deflection cone, will be investigated by varying the inside diameter of the bottom focus electrode by ± .025".

In additional experiments, the radius of faceplate curvature will be varied by ±.010" and its effect on resolution will be studied.

2.3 Deflectron Analyses and Calculations

Calculations were performed to determine the effect of various deflectron shapes on deflection sensitivity. The deflection sensitivities of four deflectron configurations were compared by summation of the reciprocals of the deflectron diameters at predetermined intervals.

Figure 1 shows four deflectron configurations used in the calculations and the results of summations are listed below

A. Large diameter conical deflectron $\frac{l}{d} = 0.296$

B. Small diameter conical deflectron $\frac{l}{d} = 0.348$

C. Large cone with cylindrical portion $\frac{l}{d} = 0.344$

D. Large cone with extended cylindrical portion $\frac{l}{d} = 0.432$

A comparison of the numerical results indicates that the best deflection sensitivity would be obtained with the deflection having extended cylindrical portion. The small diameter conical deflectron and the large diameter deflectron with cylindrical portion have similar deflection sensitivities.

The lowest overall deflection sensitivity was obtained with the conical deflectron of large diameter.

2.4 Estimates of Electron Trajectories

Figure 3 shows trajectories of undeflected electrons normally emitted at points .450", .225" and .125" from the electrical center of the photocathode. The trajectories of deflected electrons are shown in Figure 2. The electron trajectories in the focusing electrode region were obtained by constructing lines normal to the equipotentials. This method was chosen because the angles of the electron trajectories with the normals to the equipotential lines were very small (1°). The angles were calculated according to Snells Law where the electron velocities were expressed in terms of equipotential line voltages.

$\frac{V_1}{V_2} = \frac{\sin \theta_1}{\sin \theta_2}$ where V_1 and V_2 are the average voltages between two equipotential lines and θ_1 and θ_2 the angles of normal velocity components with lines perpendicular to the equipotentials.

The estimates of the deflected electron trajectories inside the deflectron were made as follows.

Assuming the deflection elements to be continuous plates of increasing axial distance the amount of deflection was calculated in five different regions along the deflectron axis by using the inverse proportion of the deflectron diamter to the amount of deflection. The initial angle of the electron velocity vector with the deflectron axis was determined from the trajectories plotted in the focusing electrode region. The electron velocity inside the deflectron was

$$V_p = \sqrt{2 \frac{Q}{m} E} = \sqrt{2 \times 1.76 \times 10^{11} \times 700} = 1.5 \times 10^7 \text{m/sec.}$$

The time of travel through the deflectron

$$t_d = \frac{L_d}{V_p} = \frac{.0288\text{m}}{1.51 \times 10^7 \text{m/sec}} = 1.91 \times 10^{-9} \text{ sec.}$$

and through each of the five regions $t = \frac{1.91 \times 10^{-9}}{5}$ sec $= 3.8 \times 10^{-10}$ sec.

Using the average deflection sensitivity of 500 volts/inch/700 volts the deflection voltages necessary to deflect the electrons into the aperture were

Ed_1 = .450" x 500 V/in = 225V

Ed_2 = .225" x 500 V/in = 112.5V

Ed_3 = .110 x 500 V/in = 55V

The amount of deflection in each of the five regions was D = Vd xt.

where $Vd = \frac{Q}{m} \times \frac{Ed}{V_p} \times \frac{1}{d}$ = deflection velocity vector

l = length of each deflection region

$l = \frac{1 \text{ defl.}}{5} = \frac{.0288}{5} \text{ m} = .0058\text{m}$

t = time of travel through one region

d = distance between deflection plates of one region

In these calculations the primary velocity vector V_p was assumed to be parallel to the deflectron axis.

Sample Calculations

$V_p = 1.51 \times 10^{-7}$ m/sec   l = .0058 m

$t = 3.8 \times 10^{-10}$ sec $d_1 \pm .0094$ m

Ed_1 = 225 V

$D = Vd \times t$

$D =$

$$D = \frac{1.76 \times 10^{-11} \times 2.25 \times 10^{2} \times 5.8 \times 10^{3}}{1.51 \times 10^{7} \times 9.4 \times 10^{-3}} \times 3.8 \times 10^{-10}$$

$D = 6.15 \times 10^{-4} m$

2.5 Test Specification and Flow Plan

A test specification to test the parameters defined in JPL Specification GMO-50391- DSN was prepared. The specification consisted of:

A. Data presentation format sheets

B. Test summary sheets

C. Instructions for performing the tests

The prepared flow plan showed the gas and heat sterilization cycles and tests to be conducted at intermediate stages of sterilization cycling.

FIG. 1

EFFECT OF THERMAL CYCLING ON LUMINOUS SENSITIVITY
BI-ALKALI PHOTOCATHODES ON 0122 GLASS SUBSTRATES

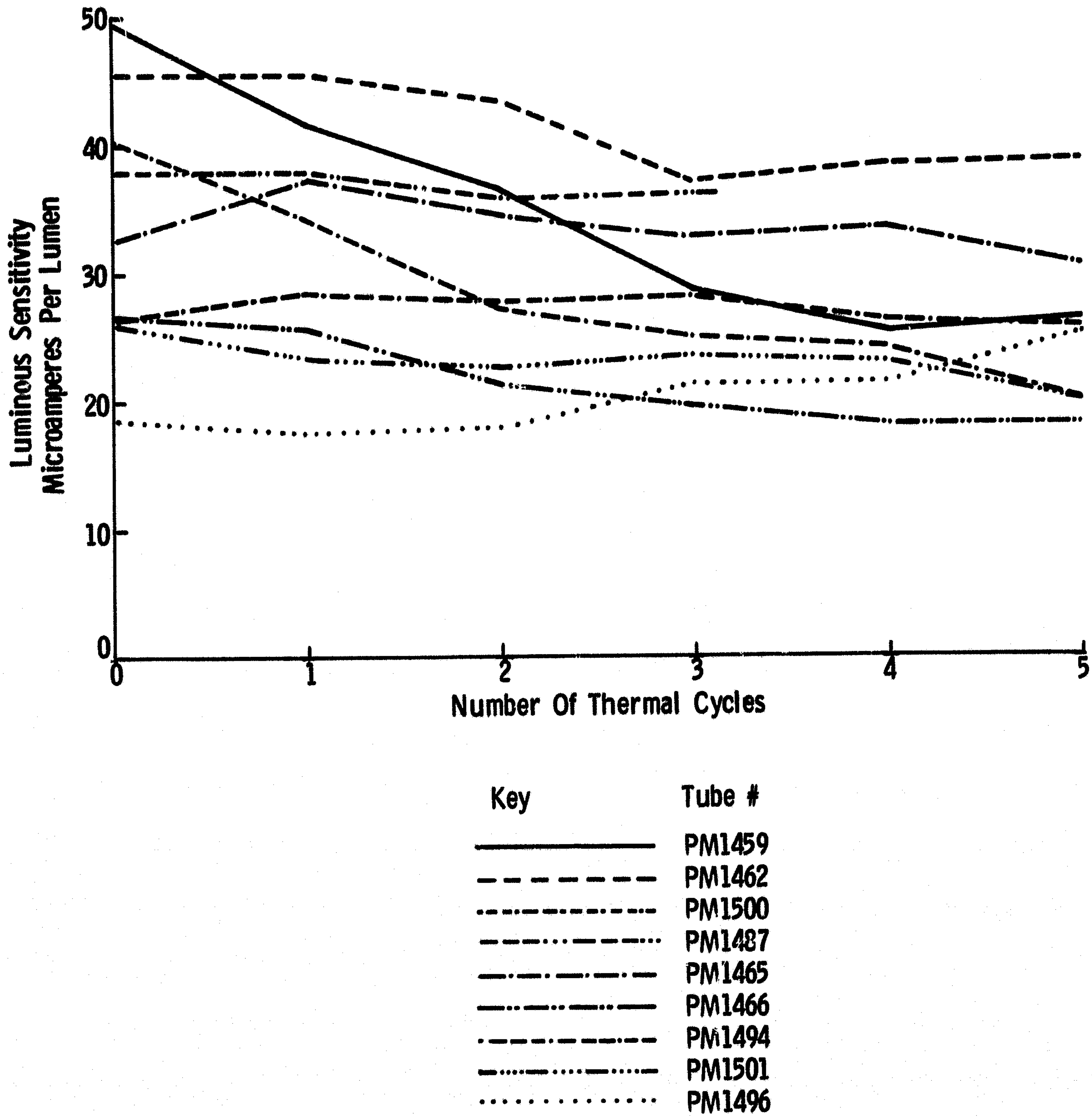


FIG. 2

EFFECT OF THERMAL CYCLING ON LUMINOUS SENSITIVITY
BI-ALKALI PHOTOCATHODES ON SAPPHIRE SUBSTRATES

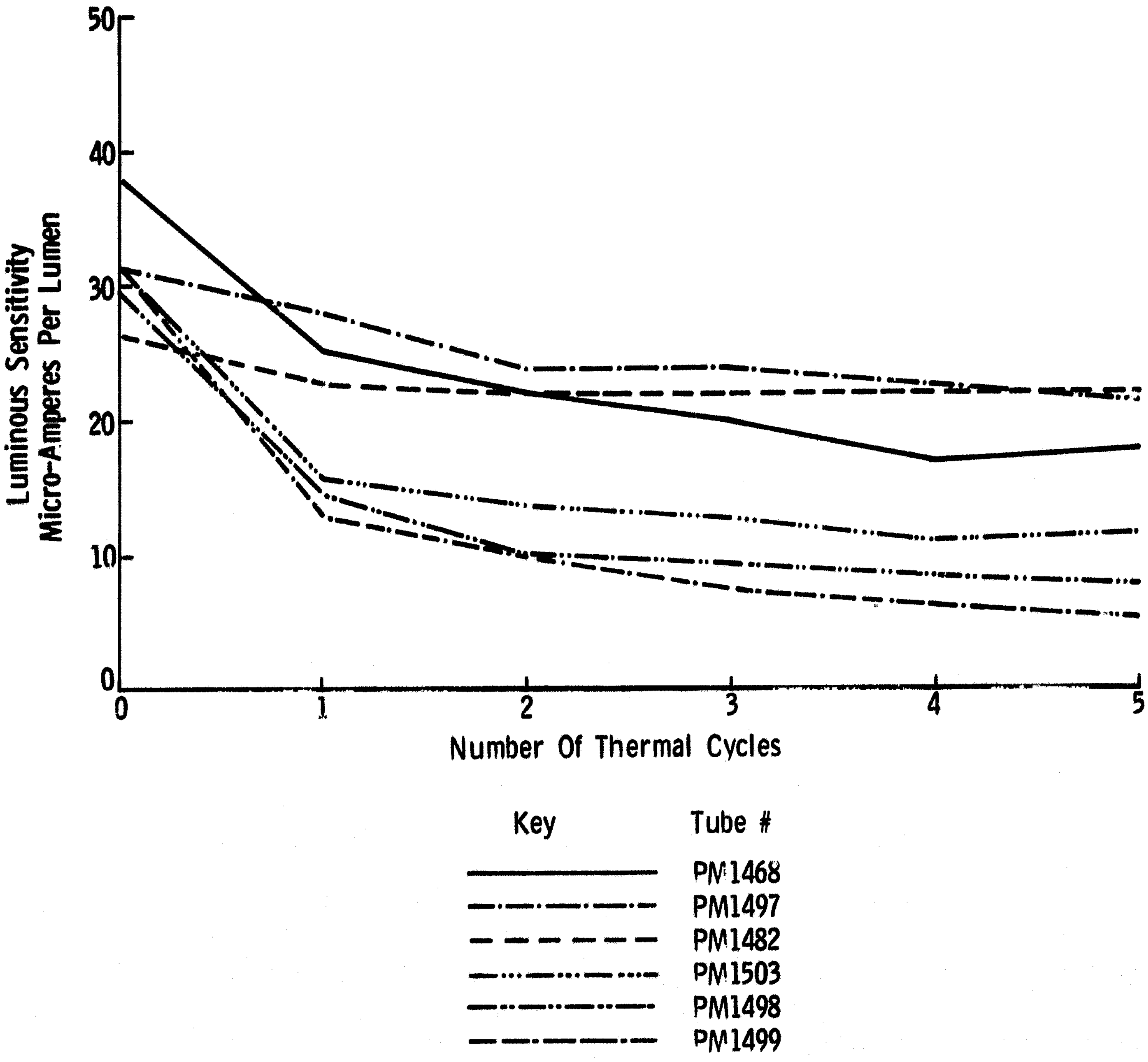
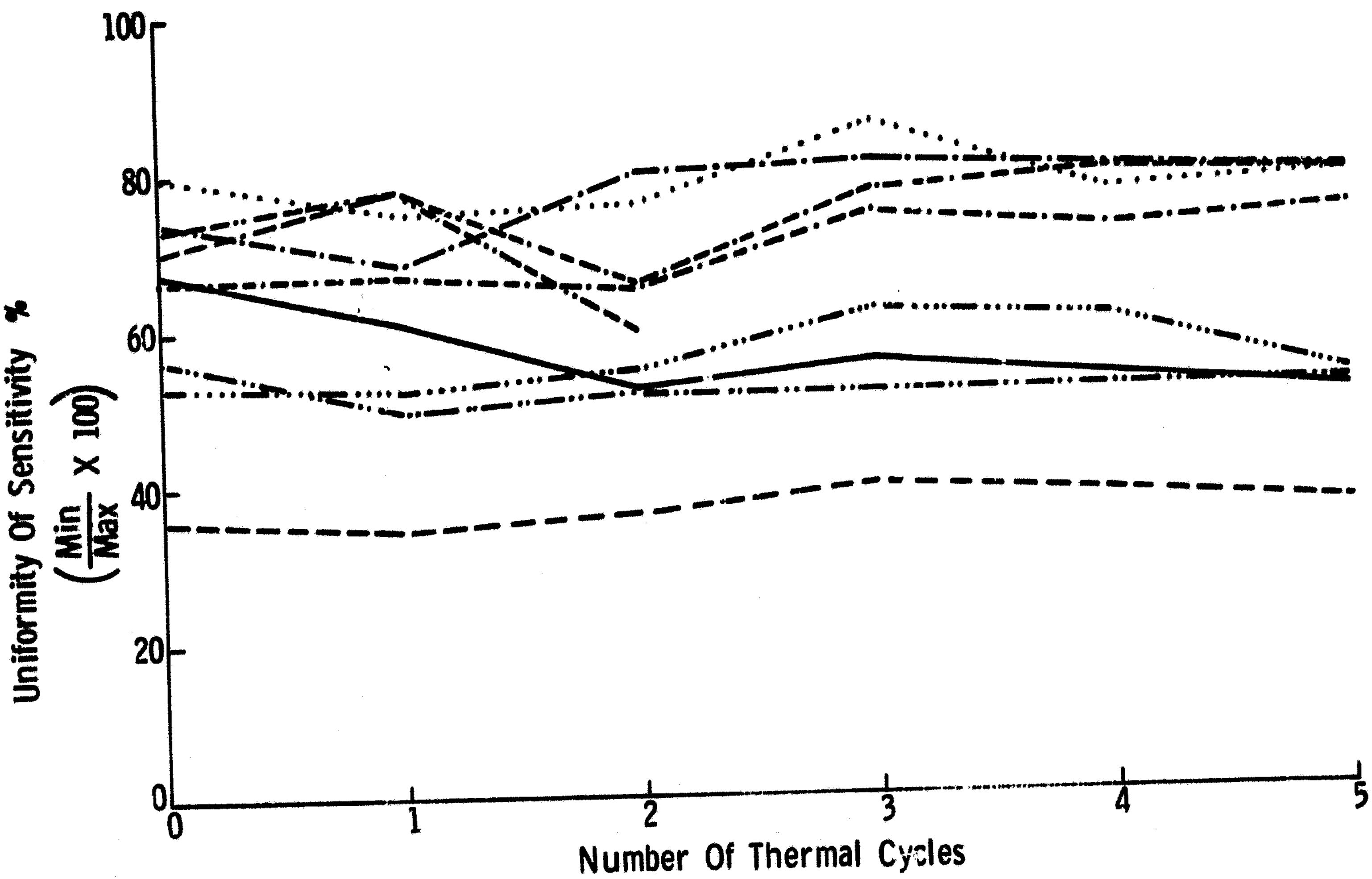


FIG. 3

EFFECT OF THERMAL CYCLING ON UNIFORMITY
BI-ALKALI PHOTOCATHODES ON 0122 GLASS SUBSTRATES



Key	Tube #
....	PM1496
——·——·——	PM1487
—·—·—·—	PM1497
———·———	PM1494
—·—·—	PM1499
————	PM1459
—··—··—	PM1466
—···—···	PM1501

FIG. 4

EFFECT OF THERMAL CYCLING ON UNIFORMITY OF SENSITIVITY
BI-ALKALI PHOTOCATHODES ON SAPPHIRE SUBSTRATES

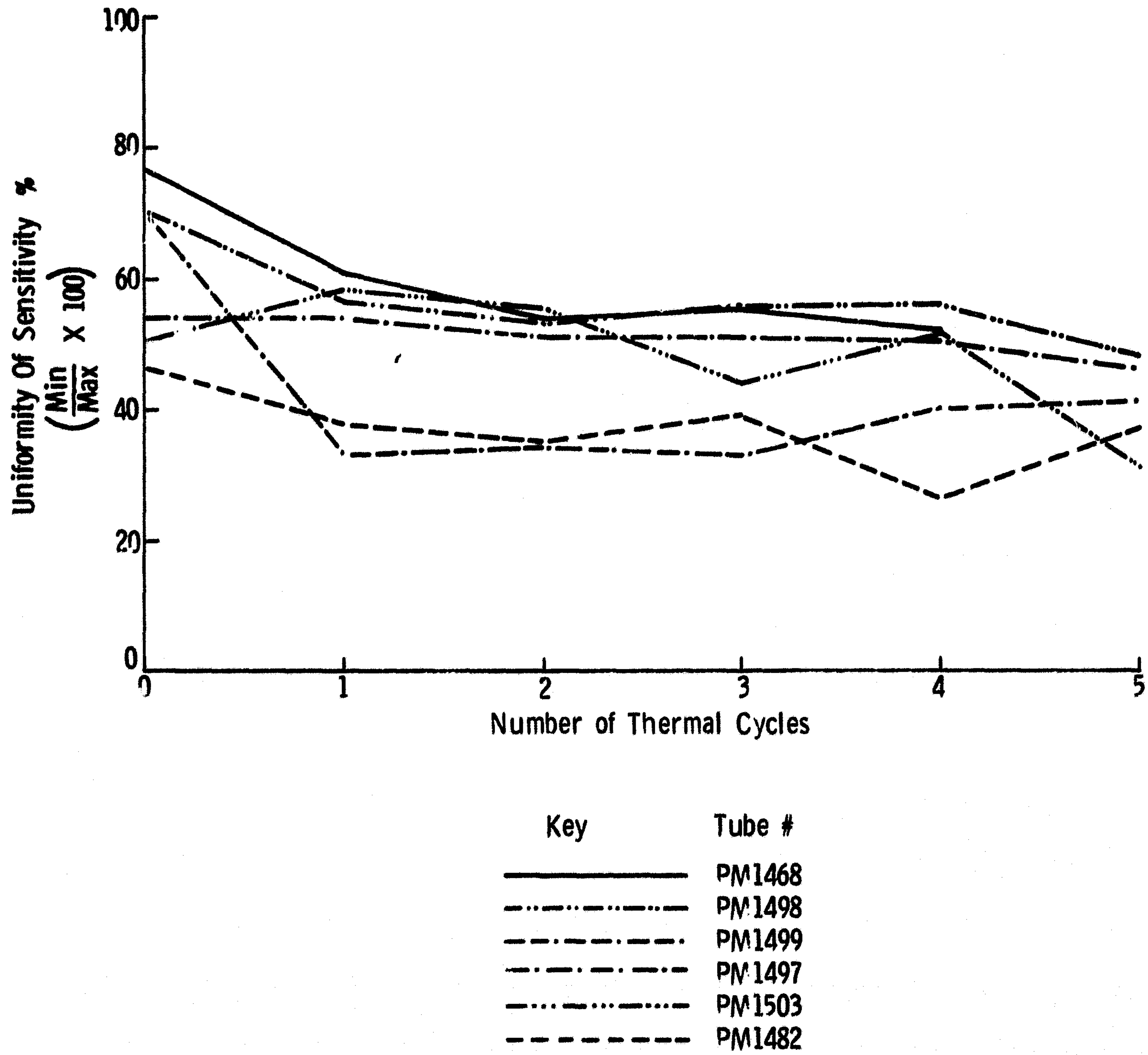


FIG. 5

PHOTOCATHODE SPECTRAL
RESPONSE CURVES

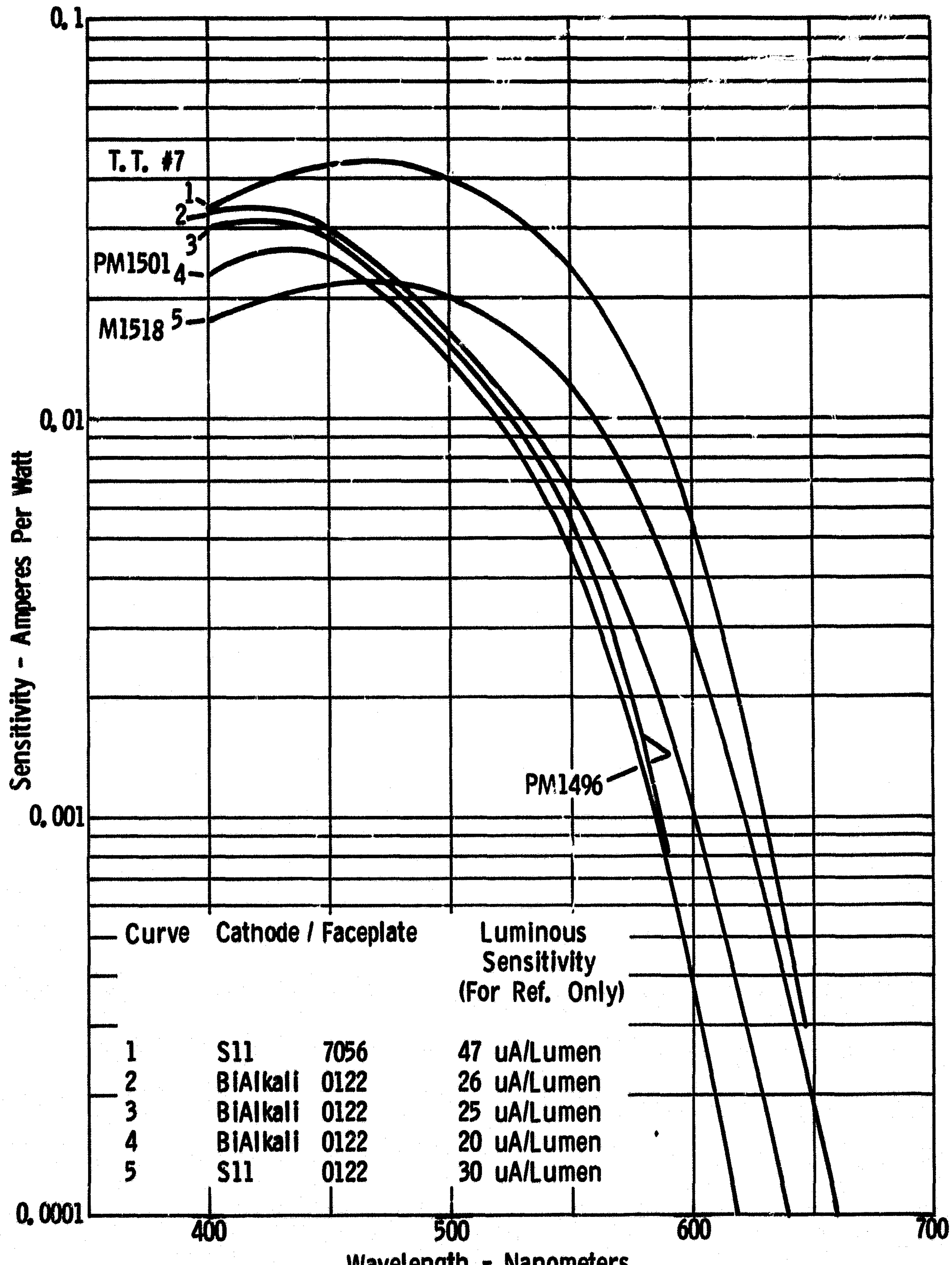


FIG. 6

PHOTOCATHODE SPECTRAL RESPONSE CURVES

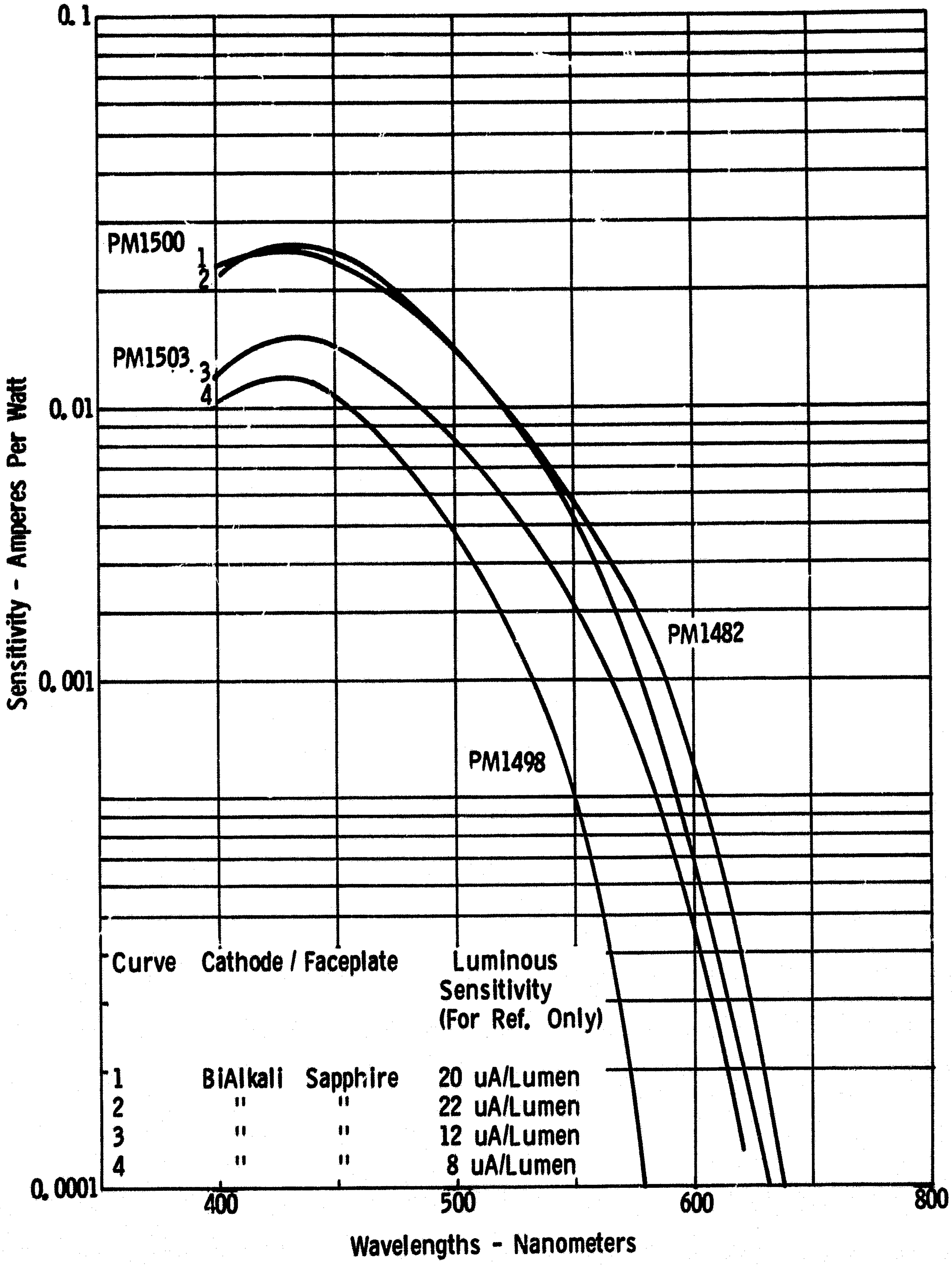
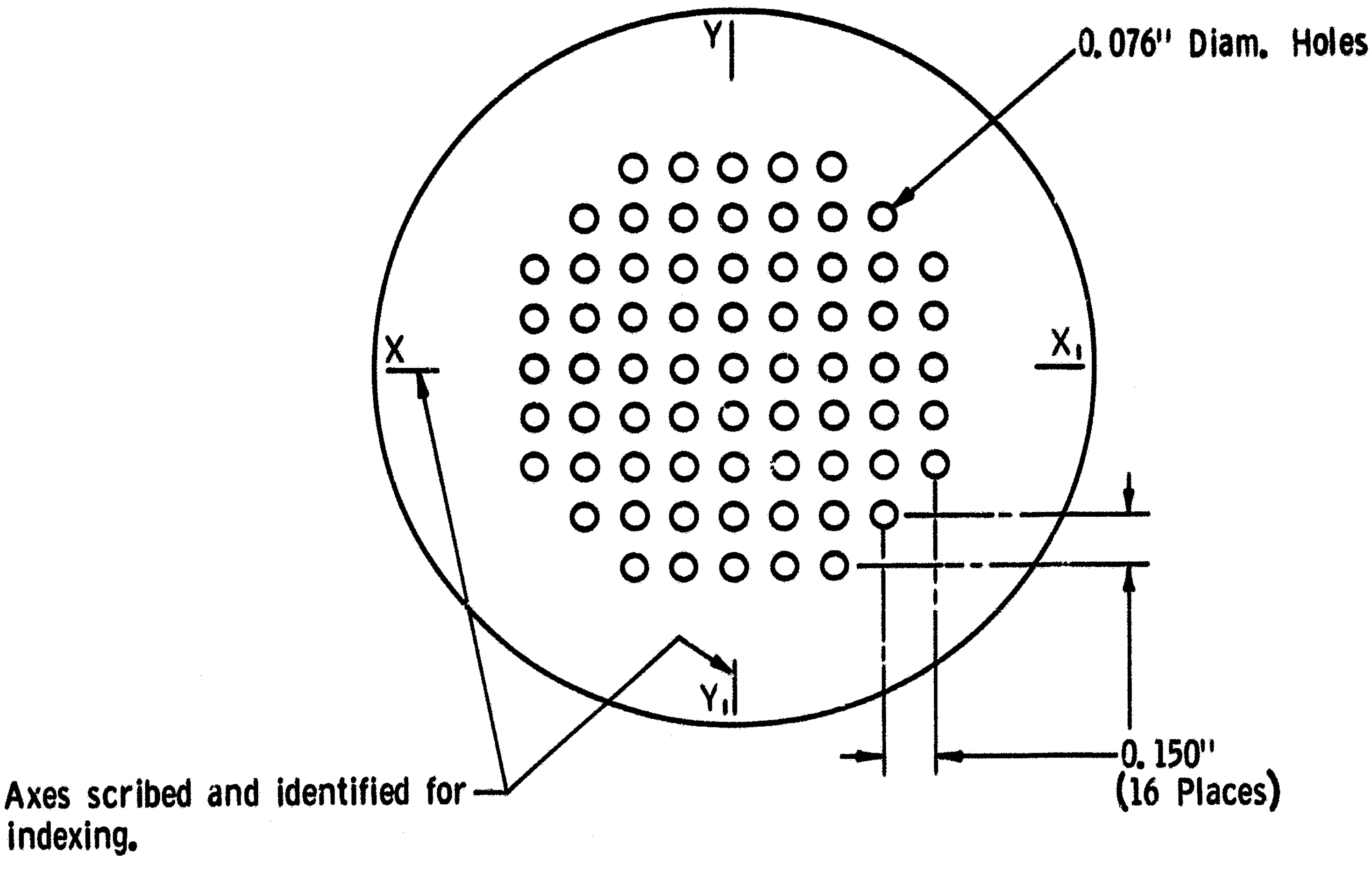


FIGURE 7
MASK USED FOR CATHODE UNIFORMITY
MEASUREMENTS



LABORATORIES

Contract No. 951477

APPENDIX II

Phase V Report

The Development of High Resolution,

High Stability Sterilizable

Image Dissector Tubes

(Photocathode Study)

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

The overall objective of the subject program is the development of a thermally sterilizable image dissector tube for use in guidance systems aboard spacecraft designed for landing on planets other than the earth. Sterilization is necessary to prevent the destruction of the biological identity of the planet by terrestrial contaminents.

The purpose of this study was the development of techniques required to produce of thermally sterilizable photocathode. That is, a photocathode in which the luminous sensitivity and the uniformity of sensitivity change less than 10% per thermal cycle.[1] Previous work undertaken within the scope of JPL Contract Number 950784 had demonstrated in an isolated instance that these objectives were feasible when using the well known bi-alkali (Na-K-Sb) photocathode.

Since it was the intent that this type of photocathode should be used in image dissectors of very precise mechanical dimensions, certain restrictions were placed, for mechanical reasons, on the choice of photocathode substrate material. In this program 0122 glass, 7056 glass and sapphire were evaluated. Early in the program the use of 7056 glass was discontinued since the results were generally

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[1] one thermal cycle = 92 hours, 135°C bake

inferior. It also happens that his glass does not readily lend itself to techniques which must be used in the manufacture of the image dissector.

Instability of photocathodes during thermal cycling can be attributed to:

a. Reaction with residual gases,
b. loss of the more volatile cathode elements from the cathode/vacuum interface,
c. reaction of the cathode elements with the cathode substrate. This includes diffusion of the cathode elements into the glass and vice versa, and
d. reaction with the residual contaminants on substrate surface.

The random and localized nature of decay in sensitivity and therefore increased non-uniformity suggested that (a) and (b) above were not the critical factors. Therefore major consideration was given to substrates and the uniformity of conditions in the preparation of substrates.

Initially it was anticipated that the non-reactive properties of sapphire would make it very desirable for use as a substrate for highly stable photocathodes. However, throughout the program bi-alkali photocathodes formed an 0122 soda lime glass consistently performed better than those on sapphire substrates.

The numerous experiments performed and the thermal cycling of the experimental devices demonstrated that a minimum luminous sensitivity of not less than 20 microamperes per lumen is a very realistic performance figure after numerous thermal cycles. It is worthwhile to note that the response of 20 microamperes per lumen bi-alkali photocathode, of the type described is greater than that of a 30 microamperes per lumen S11 photocathode at wavelengths shorter than 470 nanometers.

An additional advantage of the bi-alkali photocathode is its higher work function f(w), which results in a reduction of thermal noise and more important a reduction of photoelectron energy spread. These two factors result in improvements in signal to noise performance and electronic resolution respectively.

2. PHOTOCATHODE STUDY

2.1 General

The response to thermal sterilization of an image dissector tube serial number M1319 made within the scope of JPL Contract Number

950784 demonstrated that the objectives of the presently described work were feasible. In this case an unsuccessful attempt to deposit a photocathode was made. The deposited film was removed by baking the image dissector at 400°C after which the final photocathode was then deposited. Thermal sterilization caused only small changes in sensitivity and uniformity of sensitivity. The processes involved were therefore used as a starting point for the limited studies conducted in Phase I of this program and then in Phase V, the subject of this report.

The bi-alkali photocathodes studies undertaken in JPL Contract Number 950784 and in Phase I of this program were reviewed and an experimental program was defined. The experimental investigation was centered around the formation of sterilizable photocathodes on 0122 glass and sapphire. Both of these materials have the required optical qualities and both are readily incorporated in high precision electron optical assemblies. The previous success discussed above was achieved with 0122 glass. However, it was anticipated that the use of a chemically stable material such as sapphire would, in all probability be superior. A limited number of experiments were conducted using 7056 glass substrates to confirm previous work.

The photocathode experiments were conducted using 2" diameter photo-multiplier tubes. The sapphire tubes used standard 2" diameter 7052 cylinders with 2" diameter sapphire faceplates. Standard 7052 cylinders with 7056 faceplates were used for the 7056 substrate experiments. Since it was necessary to use frit sealing techniques in using 0122 glass substrates, the front end design of the image dissector tube was simulated.

In all experiments similar cleaning procedures were used in order to minimize variables. The effect of using alumina and Fotoceram^{R} multiplier side supports was also investigated. No correlation with photocathode performance was observed.

2.2 Pretreatment of Substrates With Antimony

In the initial experiments the effect of predepositing and removal of antimony on the substrate prior to the photocathode formation, was studied.

The procedure consisted of depositing various amounts of antimony and controlling the amount deposited by monitoring the change in optical transmission of the faceplate. This film was then "removed" by baking the photomultiplier at 400°C under high vacuum. It should be noted that it is unlikely that all the antimony was removed during this process although the remains were not visually apparent.

The performance of typical samples is shown in Table 1(a). It can be seen that the stability of the photocathodes uniformity improved with increased thickness of the predeposited antimony film. However, there was no improvement in the stability of photocathode sensitivity. The sensitivity usually fell by 40 to 50% during the first thermal sterilization cycle, followed by a reduced percentage change in succeeding thermal cycles. The effect of thermal cycling on photocathode sensitivity is shown in the data of Table 1(b).

TABLE 1(a)

The Effect of Thermal Cycling on Uniformity of Sensitivity.

Tube No.	Predeposition %*	Thermal Cycle 0	1	2	3	4
		Uniformity (Min Sens / Max Sens x 100%)				
PM 1402	0	88	61	77	76	73
PM 1405	10	82	72	67	61	62
PM 1407	30	81	75	75	73	69
PM 1419	50	66	65	65	70	

* Optical Absorption of Predeposited Layer

TABLE 1(b)

Tube No.	Predeposition %*	Thermal Cycle 0	1	2	3	4
		Sensitivity (Overall) Micro-amperes/Lumen				
PM 1402	0	45	23	20	21	21
PM 1405	10	46	21	16	16	14
PM 1407	30	42	22	17	17	17
PM 1419	50	39	24	20	17	

* Optical Absorption of Predeposited Layer

The initial non-uniformity of photocathode sensitivity can be attributed to non-uniformity of the antimony deposition during the photocathode formation and possibly a variable reaction with the substrate prior to thermal cycling. The data gathered demonstrated that pretreatment of the substrate with one of the photocathode components, i.e. antimony, reduced localized deterioration during the thermal cycles. This was predicted as forseen since the predeposition and removal of the antimony was expected to provide a chemically more uniform substrate surfaces.

2.3 Pretreatment of Substrates with Antimony and Alkali Elements

Since the predeposition and removal of antimony from the photocathode substrate prior to the formation of a photocathode resulted in more uniform sensitivity decay characteristics, credence was given the original concept that the selective deterioration of the photocathode during thermal cycling was due to reaction with the substrate or residual contaminates on the substrate.

To investigate this further, antimony (10% reduction in optical transmission) and potassium was deposited on the substrate and then removed by 400°C bake. The stability and uniformity of photocathodes formed substrates pretreated in this manner showed no improvement over those made with standard deposition procedures. To carry this further complete photocathodes were formed on the substrates and removed by baking prior to the formation of the experimental photocathode. The resultant photocathodes showed only slight improvements in sensitivity and uniformity stability in comparison to photocathode formed by conventional procedures. Although the above two experiments were not fruitful, it was reasoned that the predeposited photocathode elements were probably being removed by the baking cycle before any significant reaction with the substrate or surface contaminants could take place. Therefore a technique was devised to retain them in contact with the substrate for a larger period of time.

Since the glass (0122) has a sizable sodium content and since excesses of this has a very adverse effect on multi-alkali photocathodes, the experiments were restricted to pretreating the surface with combination of antimony and potassium.

In order to achieve the above objectives an antimony potassium photocathode was formed on the substrate. Repeated layers of antimony were then applied. Between the deposition of each antimony layer the surface was exposed to potassium vapour. This procedure was continued until the sensitivity of the surface was 50% of the maximum achieved in the entire process. A thick coating of antimony was then applied. In this procedure and antimony potassium film, is sandwiched between the faceplate and the thick antimony film. Finally the surface was baked at 400°C for one hour.

The uniformity of later photocathodes was improved by modifying the antimony deposition geometry; although this did not improve to levels presently specified for the image dissector used in Canopus Tracker; it is felt that the antimony deposition geometry of the image dissector is sufficiently good to provide photocathodes of acceptable uniformity. It should be noted that all the preceding uniformity figures were obtained from an area of approximately 1 1/4 inches square.

In order to verify the procedures developed, a number of cathodes were made on 0122 glass and sapphire substrates. The observed results through thermal cycling are shown in Figures 1 through 4. Analysis of the data presented in Figures 1 through 4 shows:

a. The initial sensitivities of the cathodes on 0122 glass averaged 34 microampere per lumen. This average fell to 25 microampere per lumen during the five thermal cycles. Only one of these cathodes had final sensitivity of less than 20 microampere per lumen.

b. The averages of the initial luminous sensitivities of the cathodes on sapphire was 33 microamperes per lumen. During five thermal cycles the average fell to 15 microamperes per lumen. Four of the six cathodes had final luminous sensitivities of less than 20 microampere per lumen.

c. The uniformity of four of the eight cathodes on 0122 glass substrates improved during five thermal cycles (average improvement 8%). Two were the same after five thermal cycles and two fell 22%.

d. The uniformity of response of all the cathode on sapphire substrate deteriorated. Average percentage change caused by five thermal cycles was 32%.

2.4 Photocathode Spectral Response

The spectral response curves of cathodes previously exposed to five thermal cycles are shown in Figure 5 and 6.

The spectral response of two S11 photocathodes were measured at the same time for reference; these are shown in Figure 5. It can be seen that the 20 microampere per lumen bi-alkali is significantly more sensitive than the 30 microampere per lumen S11 cathode at wavelengths shorter than 470 nanometers.

2.5 Photocathode Sensitivity Measurements

2.5.1 Luminous Sensitivity Measurements

The luminous sensitivity of the photocathodes was determined by exposing the entire photocathode to a known light flux (2870°K

$\pm$ 150) and by measuring the photocurrent. Luminous sensitivity was computed taking into account the specific cathode area.

2.5.2 Uniformity of Sensitivity Measurements

A mask of the design shown in Figure 7 was used for uniformity of sensitivity measurements. Matching indexing marks were provided on each tube to ensure precise locating of the mask for each test. The area under each aperture was exposed in turn to a uniform light flux. The photocurrent and therefore relative response was measured and recorded for each aperture area. Positional data was also included in order to relate antimony evaporation thickness patterns to uniformity and sensitivity.

3. THERMAL CYCLING (92 hours, 135°C Cycles)

The experimental devices were exposed to thermal cycling in the following manner.

A thermocouples was attached to the outer surface of the cathode faceplate of each tube. Outputs of the thermocouples were fed into a multi-channel chart recorder.

In order to minimize the small temperature excursions, due to the heating chamber temperature control system, the tubes were enclosed in a stainless steel shield. The temperature was raised from room to 135°C in one hour and then kept at this level for 92 hours. The tubes were cooled to room temperature before removal from oven. Cooling time was two hours. Photocathode measurements were made between thermal cycles.

4. CONCLUSION

This limited empirical study has been demonstrated that thermally sterilizable photocathodes with useful sensitivity and uniformity of sensitivity can be made on a repetitive basis. To achieve this, an initial thermal cycle is included in the manufacturing procedure.

Presently, if realistic minimum response for the bi-alkali photocathode of this type would be 0.024 amper per volt at peak, which occurs between 400 and 450 nanometers or, a minimum luminous sensitivity of 20 microamperes per lumen. This compares favorably with the peak sensitivity of 0.021 ampere per watt, at 450 nanometers, or a 30 microampere per lumen type S11 photocathode.

The limited experiments undertaken indicate that the performance of a photocathode has to be considered in conjunction with the substrate and that the use of highly stable substrates materials does not necessarily ensure good cathode stability. It is evident that interaction between a cathode and its substrate and the resulting complex is of great importance in the design of thermally stable photocathodes.

Close correspondence of the spectral response and the spectral emissivity peaks of this photocathode and sodium iodide crystal, respectively, indicate that this cathode will also be useful in photomultipliers designed for use in thermally sterilizable scintillation counting experiments.

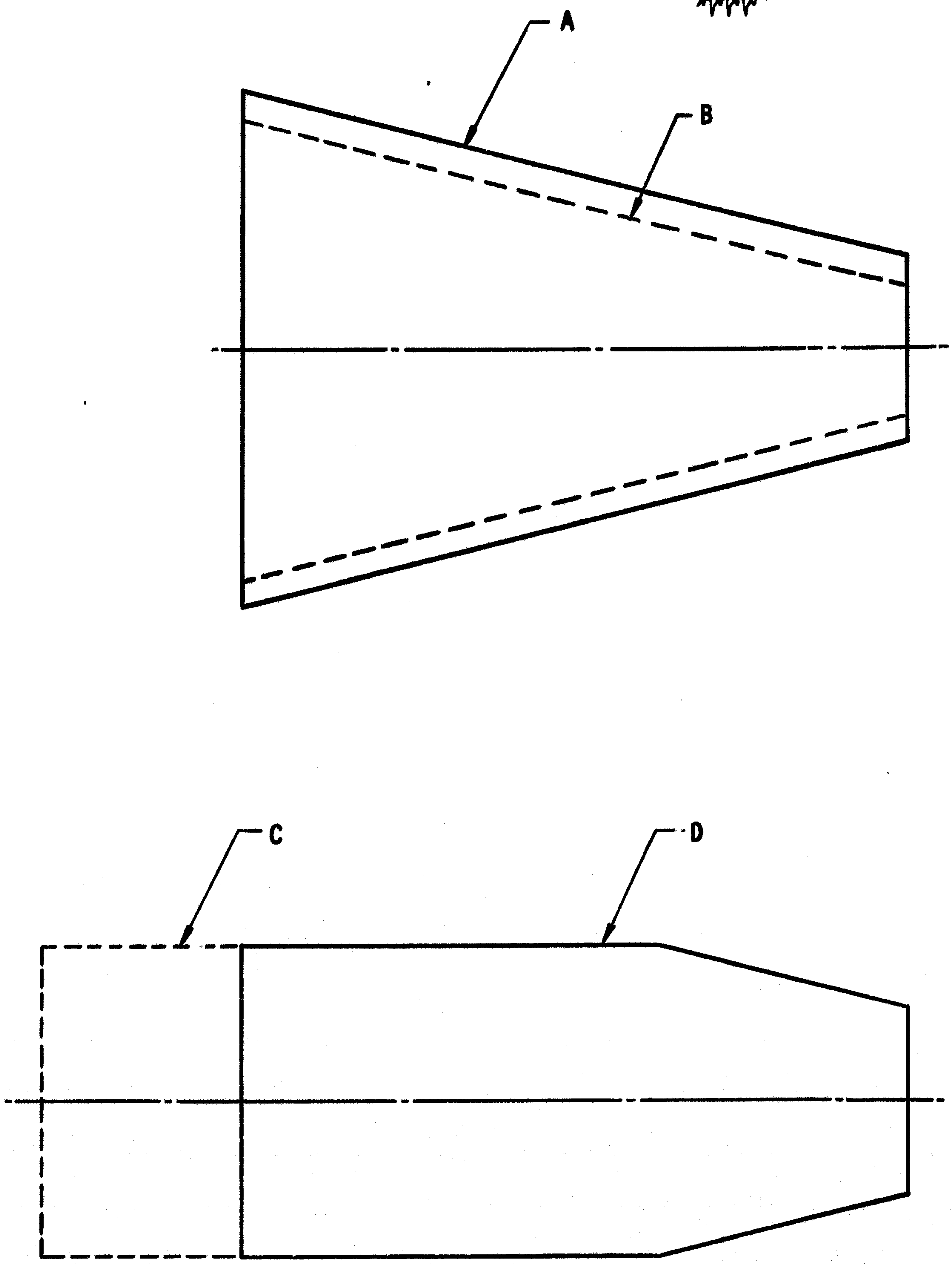

FIG. 1
DEFLECTRON CONFIGURATIONS

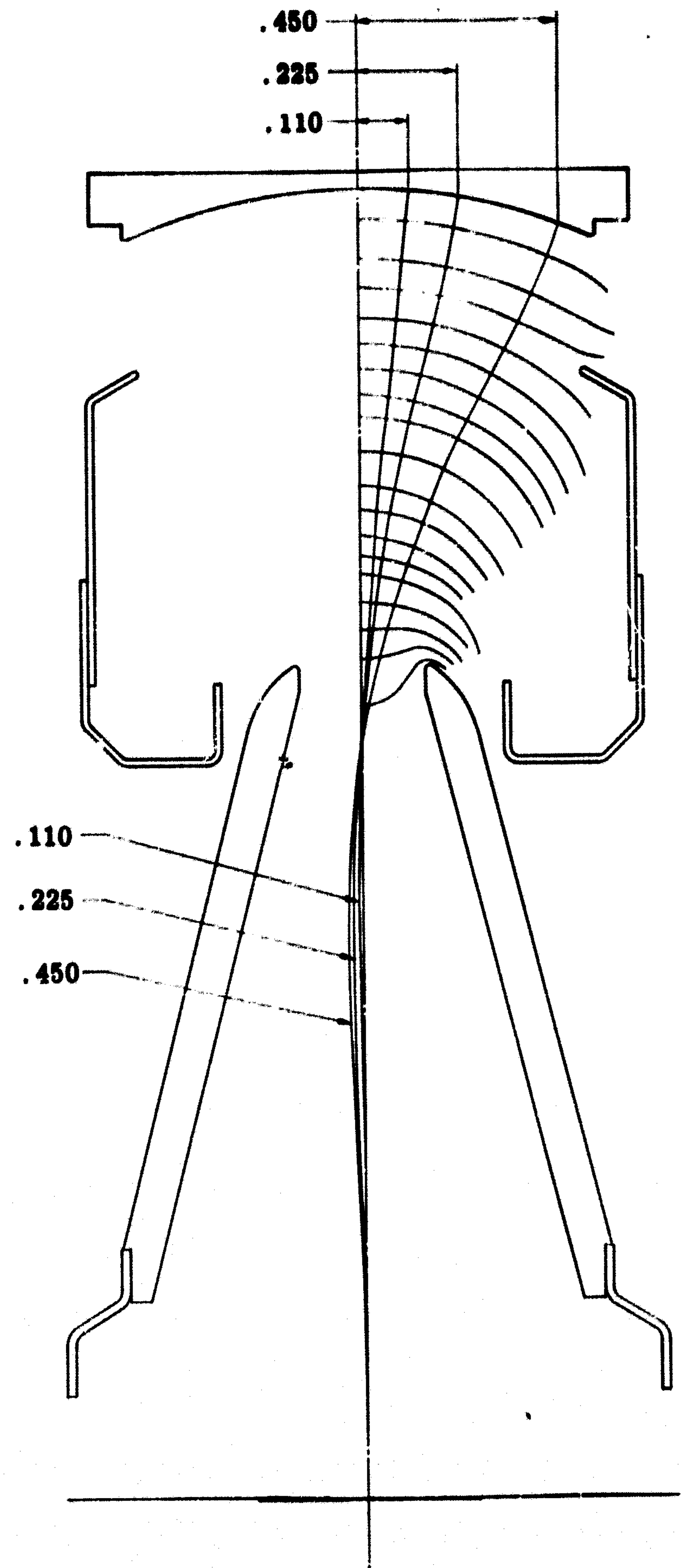

FIG. 2
TRAJECTORIES OF DEFLECTED ELECTRONS

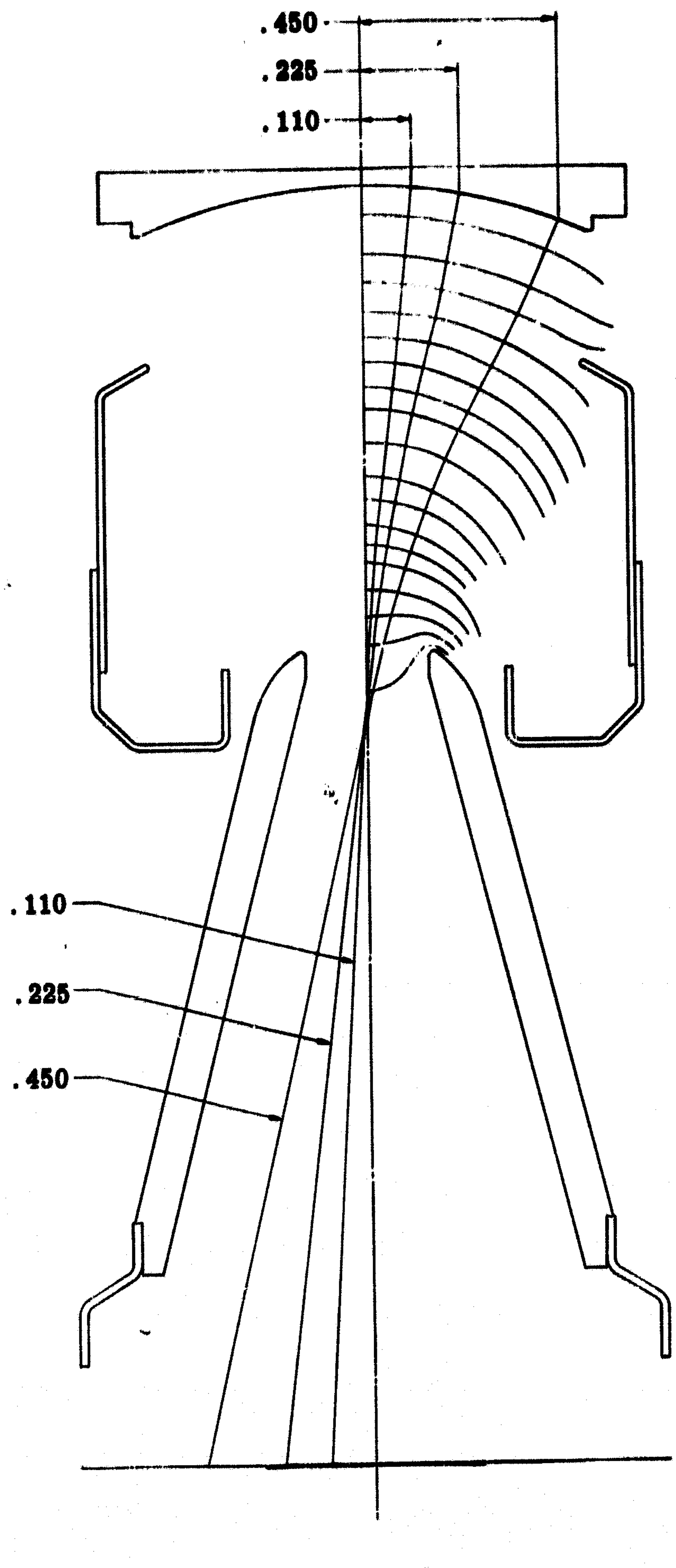

FIG. 3
TRAJECTORIES OF UNDEFLECTED ELECTRONS