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BUREAU OF ENGINEERING
NAVY DEPARTMENT

Report of

Investigation of Phototube Characteristics.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION,
Washington, D.C.

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TABLE OF CONTENTS

Page

Subject

1. AUTHORIZATION.. 1

2. OBJECT OF TEST.. 1

3. ABSTRACT OF TEST.. 1
   (a) Conclusions... 3a
   (b) Recommendations... 3a

4. DESCRIPTION OF MATERIAL AND APPARATUS UNDER TEST.................. 4

5. METHOD OF TEST.. 6

6. DATA RECORDED DURING TEST... 9

7. PROBABLE ERROR IN RESULTS... 9

8. RESULTS OF TEST... 9

9. CONCLUSIONS... 10

APPENDICES

PHOTOGRAPH OF EXTERNAL VIEW OF PHOTOMETER BOX.................. PLATE 1

PHOTOGRAPH OF INTERNAL VIEW OF PHOTOMETER BOX.................. PLATE 2

PHOTOGRAPH OF MACBETH ILLUMINOMETER............................ PLATE 3

PHOTOTUBE ELECTRICAL CIRCUIT DIAGRAM........................... PLATE 4

TABLE OF STATIC SENSITIVITY.................................... PLATE 5

TABLE OF VARIATIONAL SENSITIVITY............................... PLATE 5

TABLE OF CONDUCTANCE... PLATE 5

TABLE OF VARIATIONAL CONDUCTANCE............................... PLATE 5

TABLE OF RESISTANCE.. PLATE 6

TABLE OF VARIATIONAL RESISTANCE................................ PLATE 6

TABLE OF GAS AMPLIFICATION..................................... PLATE 6

CURRENT-ILLUMINATION CHARACTERISTIC OF RCA PHOTOTUBES........ PLATES 7 to 12

CURRENT-ILLUMINATION CHARACTERISTIC OF WESTINGHOUSE PHOTOTUBES.. PLATES 13 to 18

CURRENT-VOLTAGE CHARACTERISTIC OF RCA PHOTOTUBES............. PLATES 19 to 24

CURRENT-VOLTAGE CHARACTERISTIC OF WESTINGHOUSE PHOTOTUBES.... PLATES 25 to 30

AUTHORIZATION

1. The subject matter of this report, authorized by references (a) and (b), is concerned with the technique of phototube measurements.

Reference: (a) Eng.let. S67/38/38268(11-25-W8) of 6 Dec. 1935.
(b) Eng.let. S67/38/38268(11-26-W8) of 6 Dec. 1935.

OBJECT OF TEST

2. The object of this investigation is to present, in a comprehensive and unified manner, first, the fundamental principles of photometry which pertain directly to the determination of phototube response under varying conditions of incident flux and impressed voltage, and secondly, a detailed description of the apparatus employed. This report, containing practically all the information required for the investigation of various types of phototubes, was accumulated through reference to widely scattered sources.

ABSTRACT OF TEST

3. Two groups containing six samples each of gas phototubes, submitted by two different manufacturers for type approval tests, were employed to obtain the data presented in this report.

4. Current-Illumination Characteristic. This characteristic was obtained by holding the voltage impressed on the phototube constant at 90 volts, varying the light flux and noting the corresponding tube currents.

5. Current-Voltage Characteristic. This characteristic was obtained by adjusting the light source so that 0.1 lumen of flux fell on the phototube. The voltage across the tube was then varied and the corresponding current noted.

6. Static Sensitivity. The static sensitivity given in this report is the ratio of the direct current through the phototube at 90 volts to the incident radiant flux of 0.1 lumen.

7. Conductance of Phototube. The conductance was obtained by taking the ratio of the current through the phototube at a radiant flux of 0.1 lumen to the voltage at its terminals. Mathematically,

$$S_p = \frac{i}{e}$$

In a vacuum phototube this is a linear function of the illumination.

8. Variational Conductance of Phototube. The variational conductance was obtained by taking the ratio of the change in current through the phototube at 0.1 lumen radiant flux to the change of voltage at its terminals. As most precisely used, the term refers to infinitesimal changes as indicated by the defining equation

$$S_p = \frac{\partial i}{\partial e_p}$$

9. Resistance of Phototube. The resistance of the phototube was obtained by taking the reciprocal of the conductance. Mathematically,

$$r_p = \frac{1}{S_p}$$

10. Variational Resistance of Phototube. The variational resistance is the reciprocal of the variational conductance. Mathematically,

$$r_p = \frac{1}{S_p} = \frac{\partial e_p}{\partial i_p}$$

11. Variational Sensitivity. The variational sensitivity was obtained by taking the change in current through the phototube at 90 volts to the change in the total flux entering the tube. As most precisely used, the term refers to infinitesimal changes as indicated by the defining equation,

$$S = \frac{\partial i}{\partial \Phi}, \text{ or } \frac{\partial i}{\partial F}$$

where, Φ = total radiant flux in watts,

and F = total luminous flux in lumens. When the current changes linearly with flux, as was the case in the tests treated in this report, the variational sensitivity is independent of flux and is equal to the total sensitivity. The term total sensitivity has been defined as follows:

12. Total Sensitivity. Total sensitivity is the ratio of the current which flows through a phototube at a specified steady voltage to the total radiant flux (in watts) of specified spectral energy distribution entering the tube. Mathematically,

$$S = \frac{i}{\Phi}$$

where, Φ = total radiant flux. The total sensitivity depends upon the spectral distribution of energy of the radiation and is related to the monochromatic sensitivity as follows:

$$i = \int_0^\infty S_\nu (\nu, \Phi) \Phi_\nu (\nu) \, d\nu$$

where ν denotes the radiation frequency, and $\Phi_\nu (\nu)$ the specific radiant flux (radiant flux per frequency interval). As mentioned above, in those cases showing a linear relationship between current and flux, the total sensitivity is equal to the variational sensitivity.

13. Gas Amplification. The gas amplification is the ratio of the sensitivity of a phototube, measured at a voltage greater than the ionization potential of the gas, to the sensitivity measured at a voltage less than the ionization potential of the gas. A test for gas amplification is useful for either gas or vacuum phototubes because it is a means for estimating the residual gas pressure at a specified light flux. Since the tubes treated in this report are intended to be used at 90 volts, the currents were noted at 90 volts and 15 volts. The ratio of the currents at these two voltages gives an indication of the gas pressure and should not exceed a specified limit. No minimum limit is necessary since the sensitivity test eliminates danger of the gas pressure being too low. The readings were taken at 0.1 lumen. The value of 15 volts is considered to be a good value of anode potential to use since it is below the ionizing potential of the gas.

DESCRIPTION OF MATERIAL AND APPARATUS UNDER TEST

14. The determination of the photoelectric response of phototubes requires the following essential apparatus: a light source, a photometer box, and the phototube electrical circuit.

15. Description of Light Source. The light source was a gas-filled tungsten lamp operated at a color temperature of 2870 degrees Kelvin. This temperature was chosen in order to closely approximate the actual temperature of the lamp used as a light source for sound on film reproduction, for which purpose the phototubes treated in this report are intended to be used. This temperature, in practice, is not far from 2870 degrees Kelvin, and for that reason this value is customarily employed in testing. In order to approximate a point source as closely as possible, a standard tungsten lamp with a concentrated filament was employed. The bulb of the lamp was large enough to allow the tungsten vapor from the filament to rise and deposit thinly over the unused area of the glass. The lamp was then standardized, the filament current corresponding to a color temperature of 2870 degrees Kelvin being 5.35 amperes, and the candle power of the lamp at this temperature 14.2 candles. The lamp was operated at exactly this value of filament current because it is known that a variation of one per cent in current can produce a variation in light intensity of about six per cent. To insure constancy of filament current the standard lamp was supplied from a substantial storage battery source. The calibration of the lamp was obtained by means of an optical pyrometer of the disappearing filament type.

16. Description of Optical Pyrometer of the Disappearing Filament Type. This pyrometer had been calibrated by the Bureau of Standards with a certified accuracy of 20 degrees Centigrade for temperatures above 2000 degrees Centigrade. The pyrometer consisted of a metal tube, open at both ends, and provided with a projection serving as a means for holding an incandescent lamp. At the center of the tube was mounted the lamp which was connected in series with a battery, a rheostat, and a milliammeter. The relationship between the milliamperes flowing through the filament and the temperature of the filament was known. The calibration of the standard lamp which was intended to be used as the source of light for the phototubes was carried out as follows: The pyrometer lamp was first adjusted to that value of current which made the filament to have a temperature of 2870 degrees Kelvin. The operator then held the pyrometer in front of his eye and, looking through, observed the filament superimposed on the lamp to be calibrated as background. The current through the pyrometer lamp was held constant while the current through the other lamp was varied progressively until the two separate filaments appeared equally bright. The current value at which this occurred was noted and thereafter maintained constant.

17. Description of the Photometer Box. Plates 1 and 2 are photographs of the photometer box. The box is simply an enclosure from which every trace of extraneous light is carefully excluded. At one end of the box is mounted the standard lamp and at the other end the phototube. The lamp socket is conveniently mounted on a carriage which can be moved toward or away from the phototube just as in the usual photometer practice. Baffles with central apertures are placed between the lamp and the phototube to exclude extraneous light and to confine the incident flux within

the proper solid angle. The distance between the filament and the phototube is 9.0 inches, which is considered to be the minimum desirable limit for permitting the use of the inverse square law in computing the illumination. A scale is also provided by means of which the distance between filament and phototube is accurately measured.

18. Description of Phototube Enclosure. Plate 1 shows a photograph of the phototube enclosure employed. The phototubes were tested while within this enclosure, which is lightproof and has a circular window of 0.50 inches diameter. The whole of this enclosure, both inside and out, is coated with a dead black covering. The plane of the window is parallel to the plane of the vertical edges of the phototube cathode and is spaced about 5/32 inches from the glass wall of the tube. The tube enclosure is mounted on a suitable tube socket and is so arranged that, with the phototube fully inserted in the socket, the center of the window is 2.44 inches above the lower edge of the tube base. In addition, there is also provided a light shield parallel to the plane of the above named window and spaced 11/16 inch therefrom in the direction of the light source. Piercing this shield is a 5/8 inch diameter circular opening having its axis coincident with the axis of the window of the phototube enclosure. To insure precision in determining the luminous flux incident upon the phototube cathode the phototube enclosure has its aperture exposing only a definitely described portion of the cathode. The diameter of this aperture is 0.50 inch as mentioned before.

19. Description of Illuminometer. The measurement of the intensity of the illumination of the standard lamp falling on the phototube is made by means of the Macbeth Illuminometer manufactured by the Leeds & Northrup Company. In using this illuminometer to measure illumination intensities a test plate is placed at the point in the plane where the illumination value is desired. This test plate is made of a white material of good diffusing qualities. Care has been used by the manufacturer in the selection of this plate to insure, as far as possible, its coefficient of reflection being constant for all angles of incident light. The test plate becomes a secondary source of light, the brightness of which is compared with that of a translucent screen within the instrument which is illuminated to a known intensity by a Mazda lamp. The scale of the instrument is calibrated in foot-candles, and when standardized it allows for the absorption of the test plate; hence the device is direct reading and the values secured give the intensity of illumination on a given surface. Plate 3 shows a photograph of the Macbeth Illuminometer. The scale of the illuminometer is from 1 to 25 foot-candles. In order to increase the range of measurement, absorbing screens are provided. These screens are made of Wratten filters which widely extend the normal range of the instrument. Screens of various densities may be used, either neutral or colored, for selective absorption. These screens are very easily inserted or removed. The total range of the instrument with the two screens ordinarily provided is from about 0.02 to 1200 foot-candles, but this range may be extended by additional screens, two or three thousand maximum and minimum if desired.

The intensity of any source of illumination may be determined by placing the test plate of the Macbeth Illuminometer at a known distance from the source, measuring the illumination intensity in foot-candles upon the test plate and then computing the candle-power by multiplying the scale values by the square of the distance of the test plate from the unknown source (law of the inverse squares).

20. Diagram of Connections. Plate 4 shows the electrical circuit connections employed. R is conventionally a one-megohm resistor whose function is to limit the current through the tube in the case of a glow discharge in gas phototubes. It is also useful in simulating the actual circuit conditions of the tube in use. The direct-voltage drop in R is ordinarily negligible, but may be corrected for where accurate results are desired. The ammeter A is a multiscale microammeter.

METHOD OF TEST

21. In order that the results obtained may stand out clearly in their various relationships, and the method employed clarified, it is eminently desirable to present at this point the fundamental defintions, units, and symbols used. The definitions given below are abstracted from the list of photometric definitions standardized by the Illuminating Engineering Society and the American Standards Association.

22.

(a) Luminous Flux - Luminous flux is the rate of flow of radiation evaluated with reference to visual sensation, and is expressed in lumens.

(b) Luminous Intensity - The luminous intensity of a point source in any direction is the flux per unit solid angle (one steradian) emitted by the source in that direction.

(c) Illumination - The illumination at any point of a surface is the luminous flux density at that point, or when the illumination is uniform, the incident flux per unit of intercepting area.

(d) Lumen - The lumen is the unit of luminous flux. It is equal to the flux emitted in a unit solid angle by a uniform point source of one international candle.

(e) Candle Power - Candle power is luminous intensity expressed in candles.

(f) Foot-Candle - The foot-candle is a unit of illumination, and is equal to one lumen per square foot.

23. Mathematical Discussion. The table below giving the photometric quantities, the names of the units and their symbols, is convenient:

Photometric Quantity	Name of Unit	Symbols
(a) Luminous flux	Lumen	F
(b) Luminous intensity	Candle	$I = \frac{\partial F}{\partial \omega}$
(c) Illumination	Foot-candle	$E = \frac{\partial F}{\partial A}$

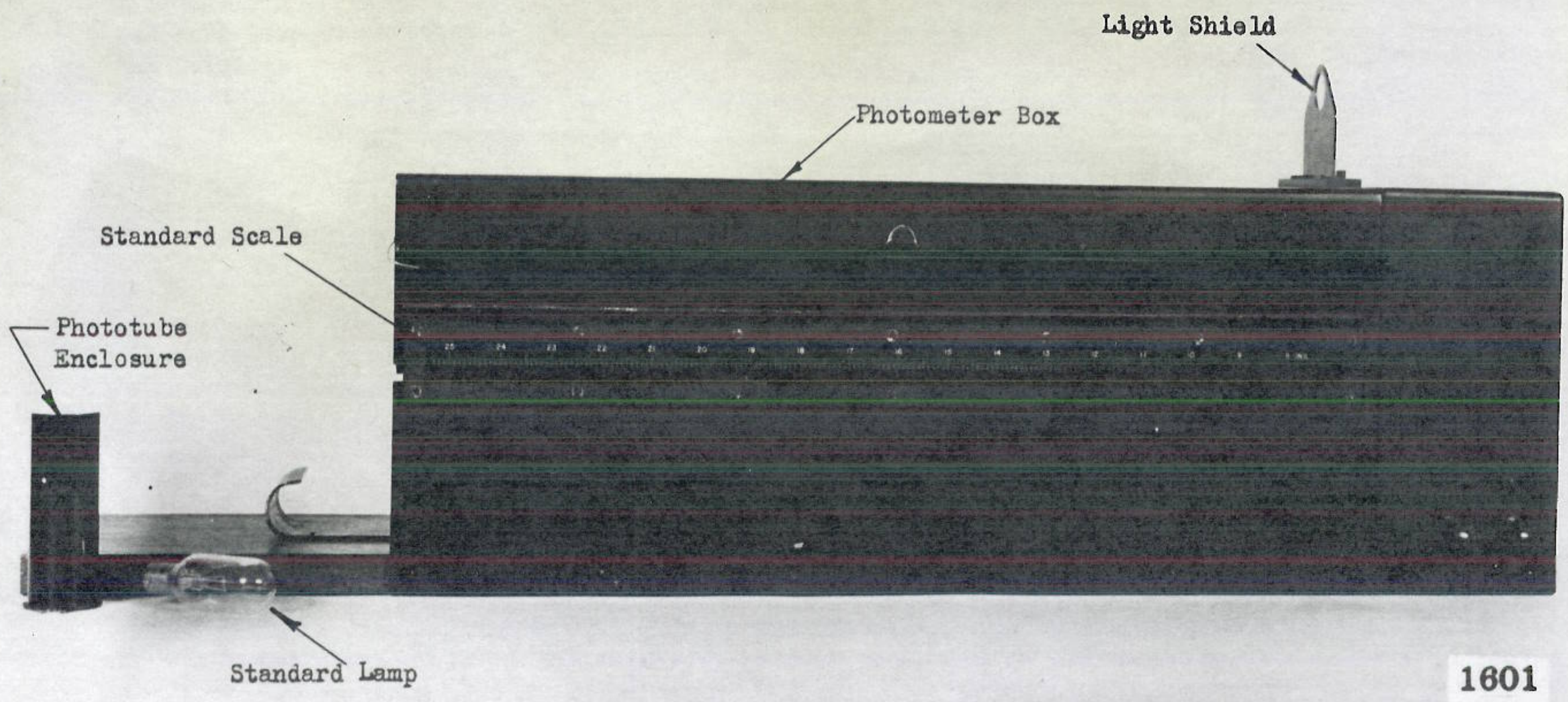
Light Shield
Photometer Box
Standard Scale
Phototube
Enclosure
Standard Lamp
1601

Plate 1

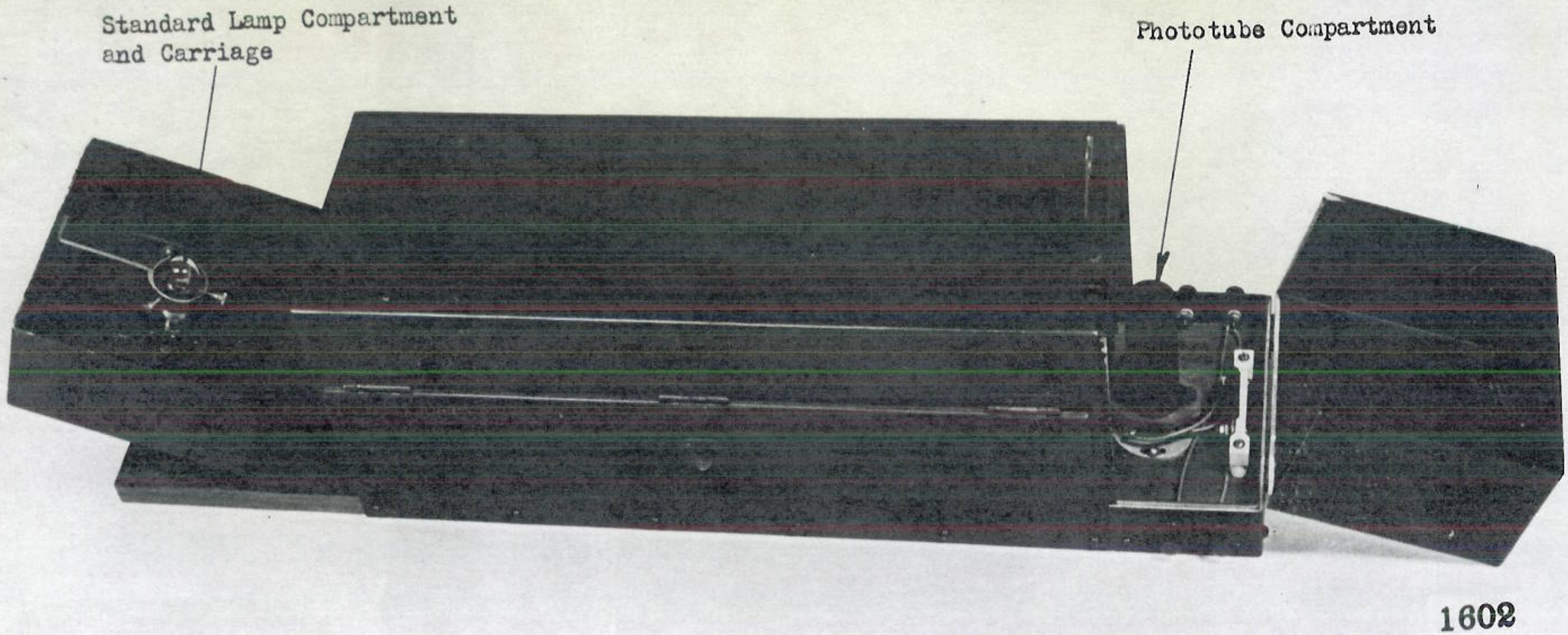
Standard Lamp Compartment and Carriage
Phototube Compartment
1602
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Plate 2

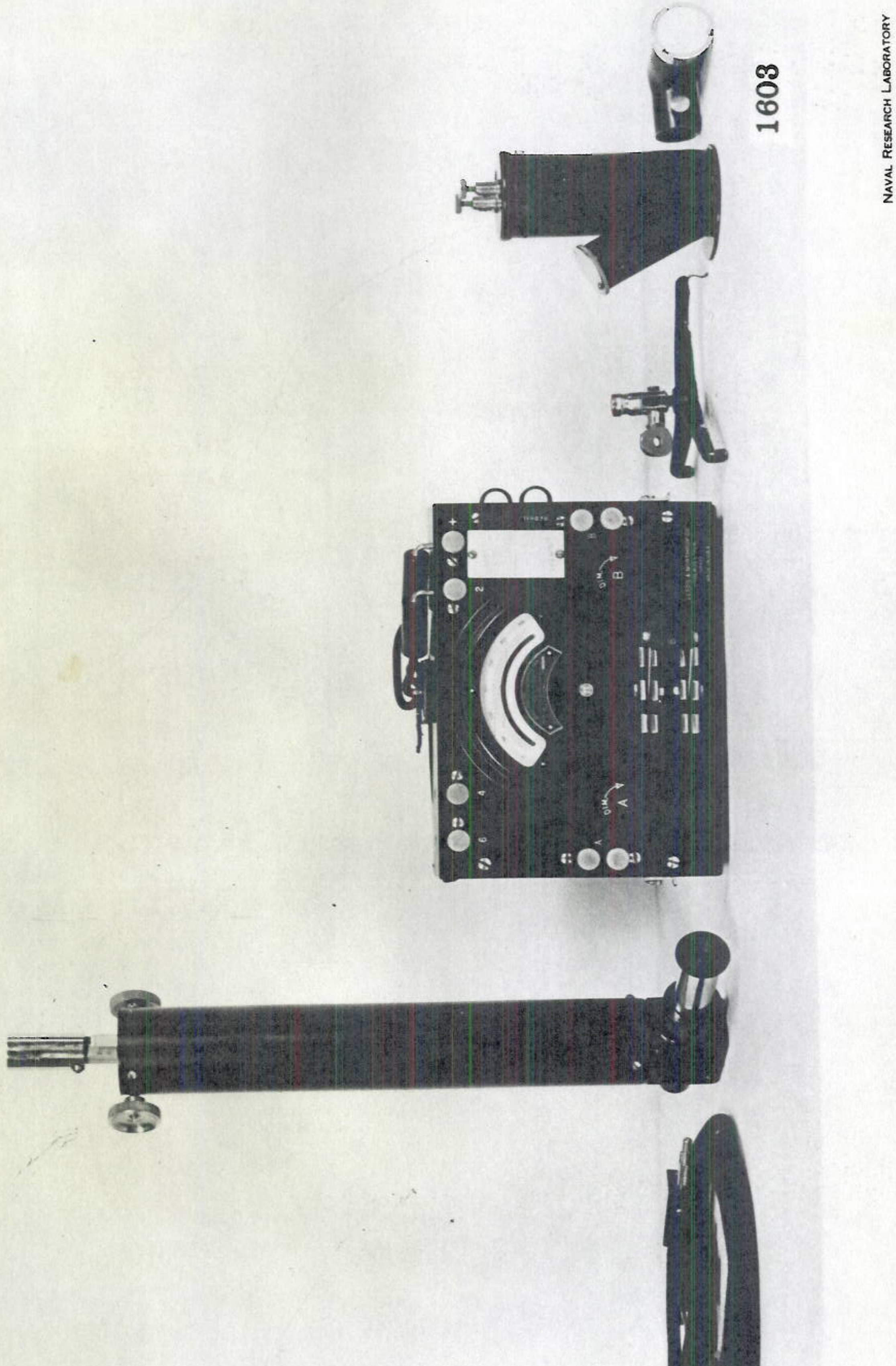
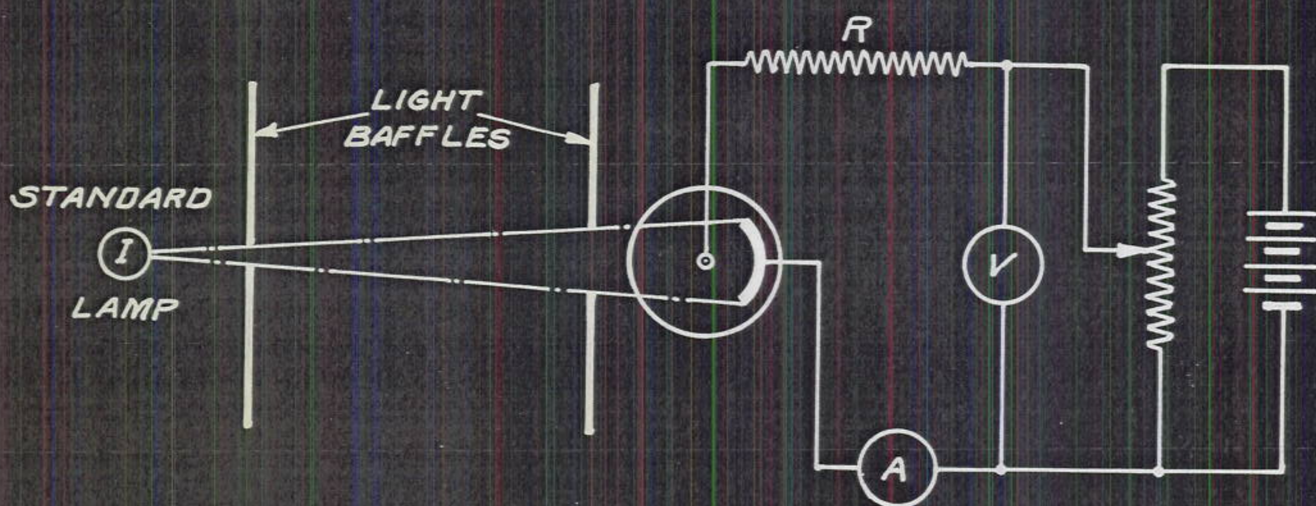

1603
NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON D.C.

Plate 3 1255



ELECTRICAL CIRCUIT FOR PHOTOTUBE TESTS.

PLATE 4

Static Sensitivity in Microamperes per Lumen at 90 Volts and 0.1 Lumen

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	55	99
2	61	108
3	48	69
4	62	68
5	73	116
6	73	79
Average	62	90

Variational Sensitivity in Microamperes per Lumen at E = 90 volts.

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	42.5	90.0
2	47.5	80.0
3	35.0	62.5
4	47.5	55.0
5	57.5	95.0
6	62.5	60.0
Average	48.8	73.8

Conductance in Micromhos at 0.1 Lumen

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	0.0650	0.1235
2	0.0727	0.1364
3	0.0562	0.0830
4	0.0740	0.0817
5	0.0883	0.1470
6	0.0883	0.0962
Average	0.0741	0.1130

Variational Conductance in Micromhos at 0.1 Lumen

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	0.17	0.28
2	0.16	0.38
3	0.14	0.29
4	0.13	0.26
5	0.20	0.30
6	0.18	0.25
Average	0.163	0.293

PLATE 5

Resistance in Megohms

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	15.37	8.09
2	13.85	7.33
3	17.75	12.03
4	13.52	12.06
5	11.32	6.76
6	11.32	10.38
Average	13.85	9.44

Variational Resistance in Megohms

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	5.88	3.57
2	6.25	2.63
3	7.14	3.45
4	7.69	3.85
5	5.00	3.33
6	5.56	4.00
Average	6.25	3.47

Gas Amplification at 0.1 Lumen

Phototube No.	RCA Radiotron Co.	Westinghouse Lamp Co.
1	5.63	8.50
2	5.63	11.40
3	5.66	8.33
4	5.46	8.00
5	6.55	10.00
6	5.39	9.50
Average	5.72	9.29

PLATE 6

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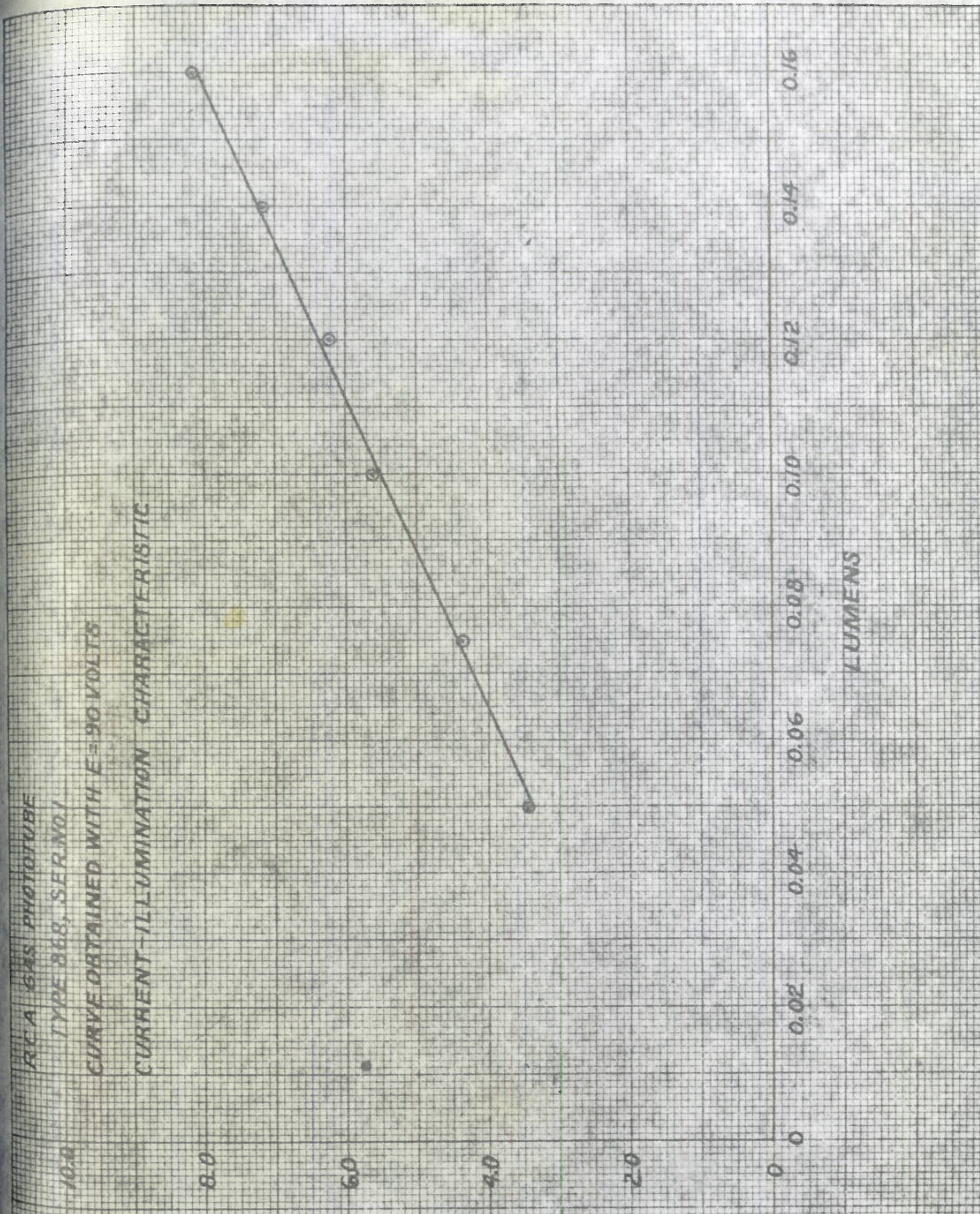

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PLATE 7

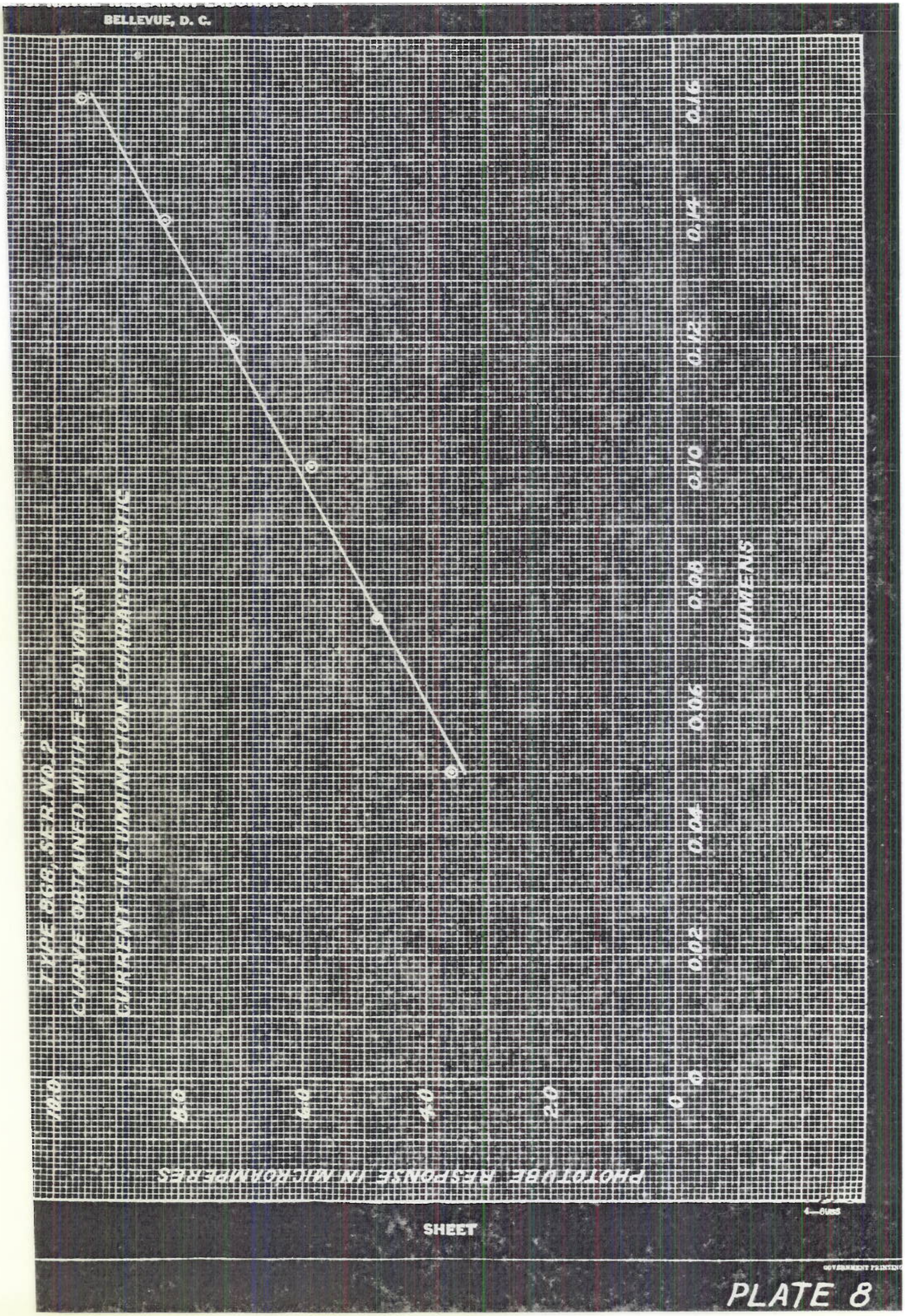
BELLEVUE, D. C.
TYPE 868, SER. No. 2
CURVE OBTAINED WITH E = 90 VOLTS
CURRENT ILLUMINATION CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
LUMENS
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
2.0
4.0
SHEET

PLATE 8

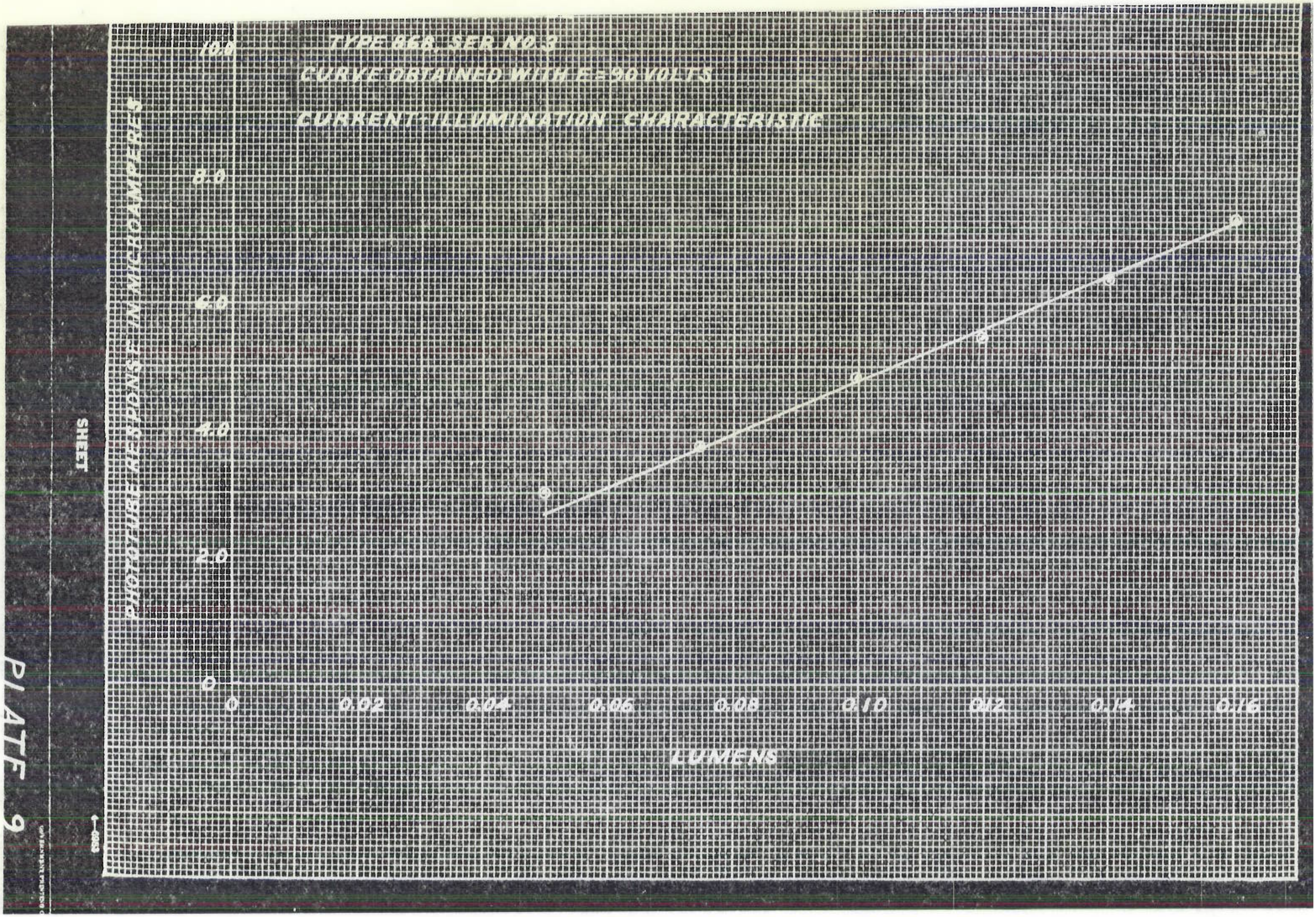
TYPE 868, SER. NO. 3
CURVE OBTAINED WITH E=90 VOLTS
CURRENT ILLUMINATION CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
10.0
8.0
6.0
4.0
2.0
0
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
LUMENS
SHEET

PLATE 9

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DATE

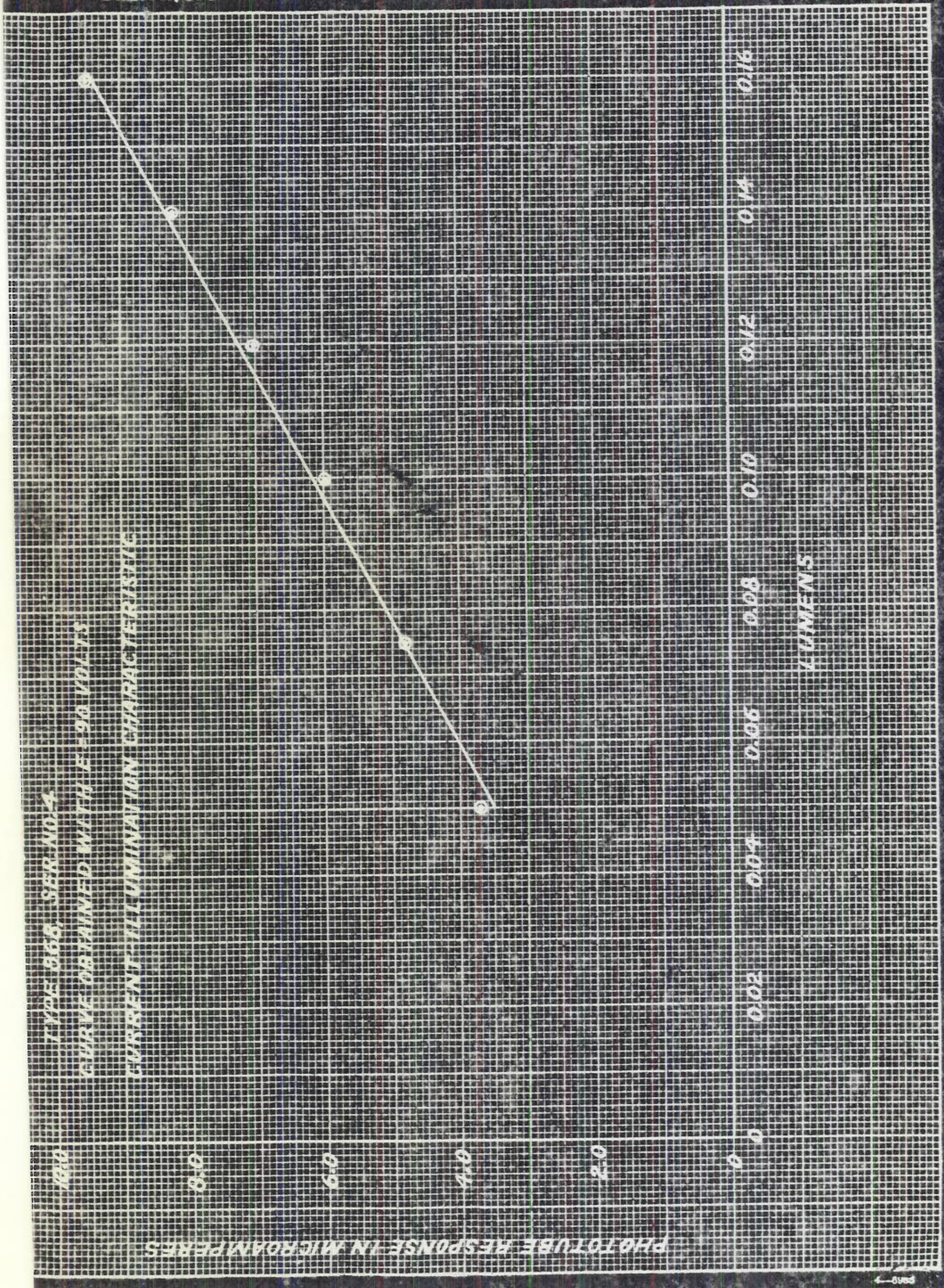

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PLATE 10

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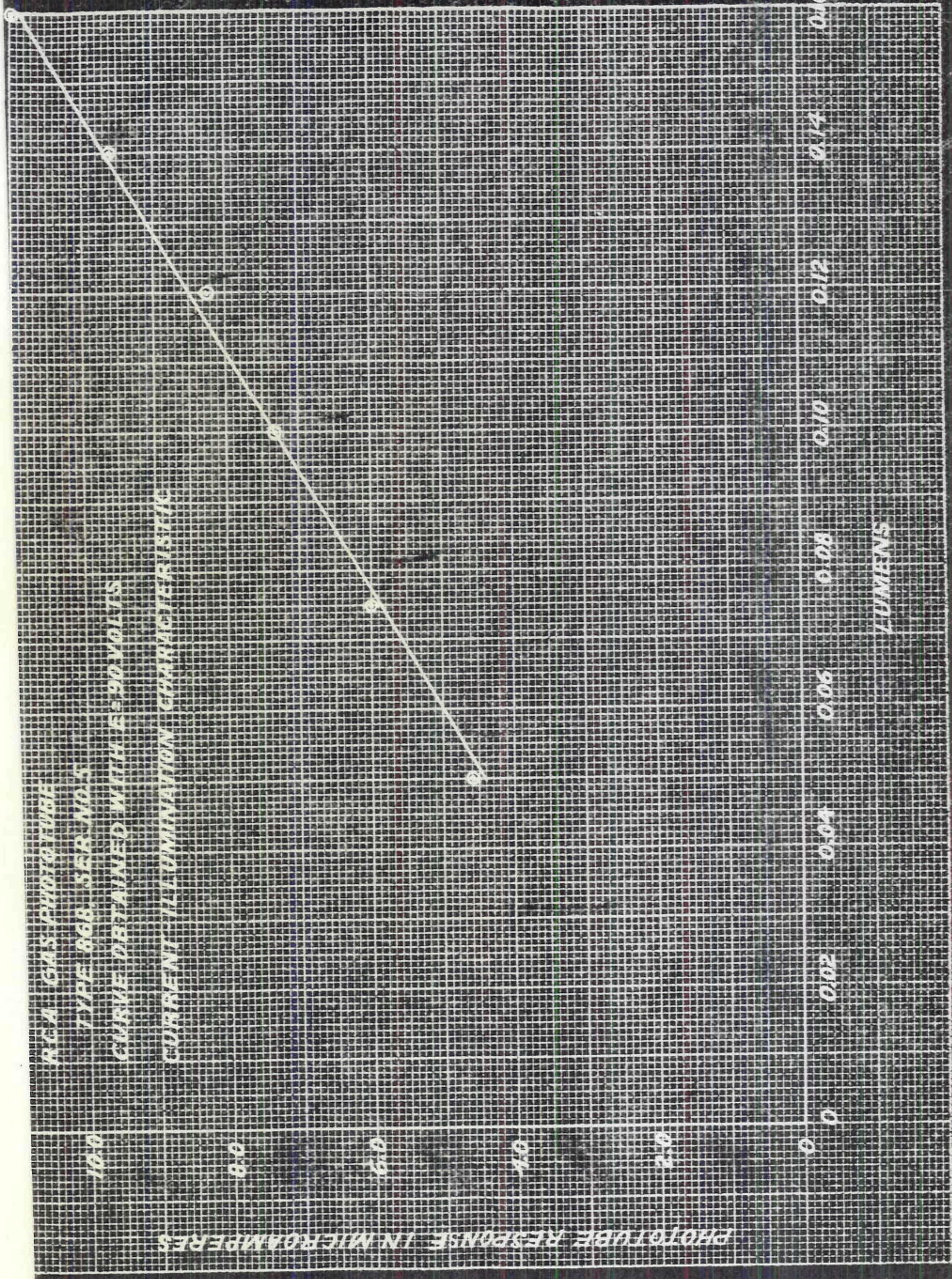

PLATE 11

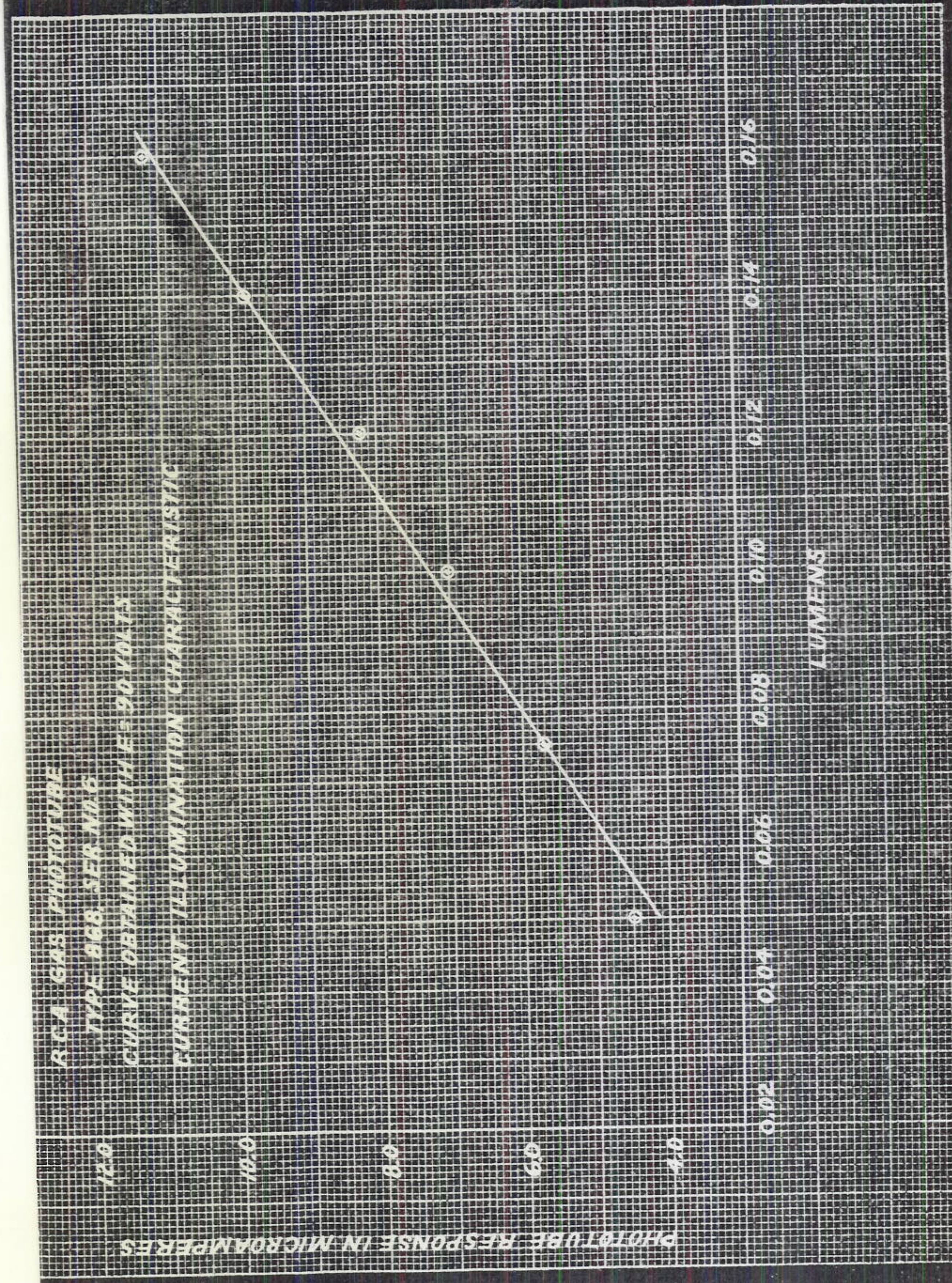
RCA GAS PHOTOTUBE
TYPE 868 SER. NO. 6
CURVE OBTAINED WITH E=90 VOLTS
CURRENT ILLUMINATION CHARACTERISTIC
12.0
10.0
8.0
6.0
4.0
PHOTOTUBE RESPONSE IN MICROAMPERES
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
LUMENS

PLATE 12

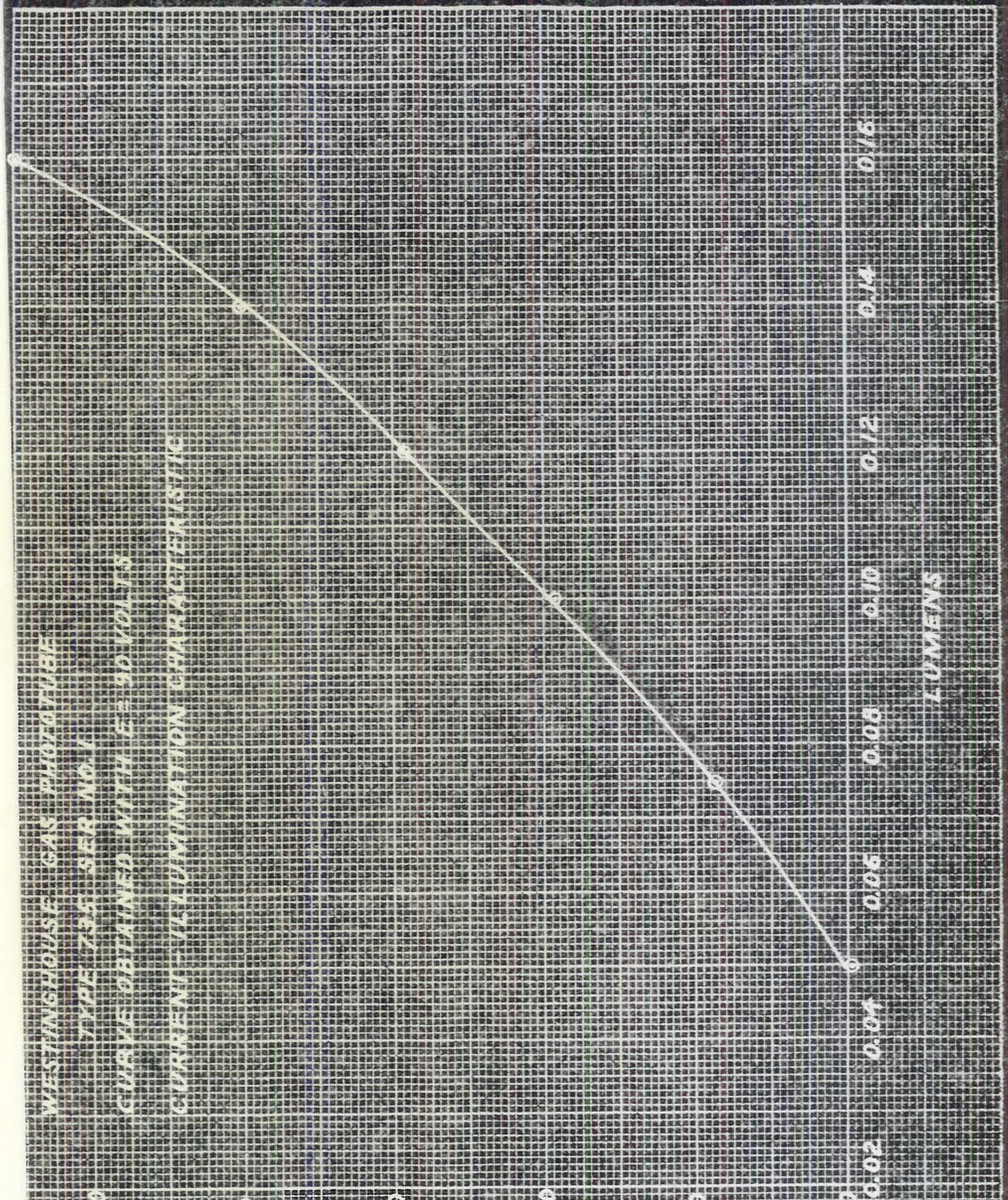
WESTINGHOUSE GAS PHOTOTUBE
TYPE 735 SER NO. 1
CURVE OBTAINED WITH E=90 VOLTS
CURRENT ILLUMINATION CHARACTERISTIC
16.0
14.0
12.0
10.0
8.0
6.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
LUMENS
PHOTOTUBE RESPONSE IN MICROAMPERES

PLATE 13

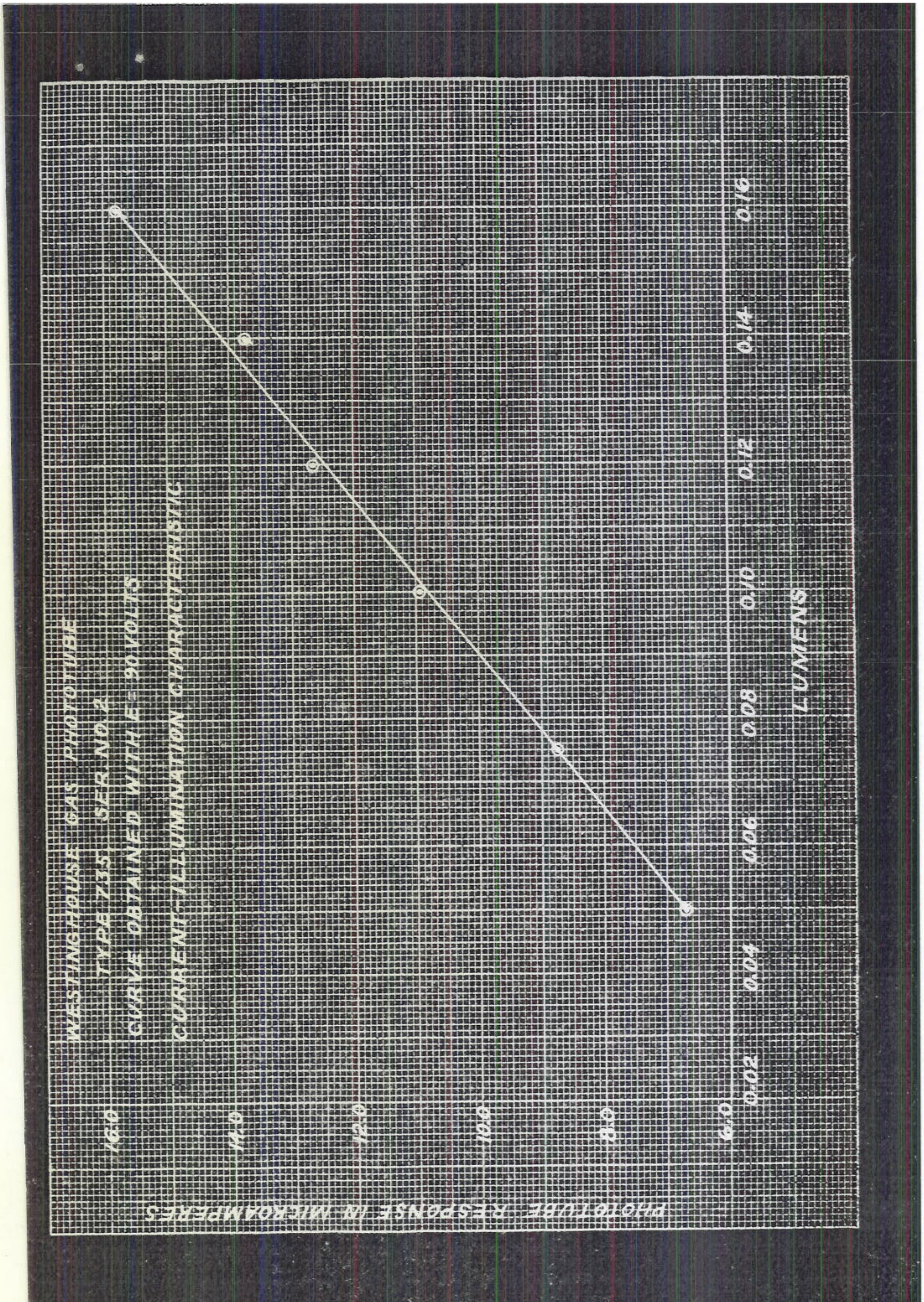
WESTINGHOUSE GAS PHOTOTUBE
TYPE 735 SER. NO. 2
CURVE OBTAINED WITH E = 90 VOLTS
CURRENT-ILLUMINATION CHARACTERISTIC
16.0
14.0
12.0
10.0
8.0
6.0
PHOTOTUBE RESPONSE IN MICROAMPERES
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
LUMENS

PLATE 14

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DATE

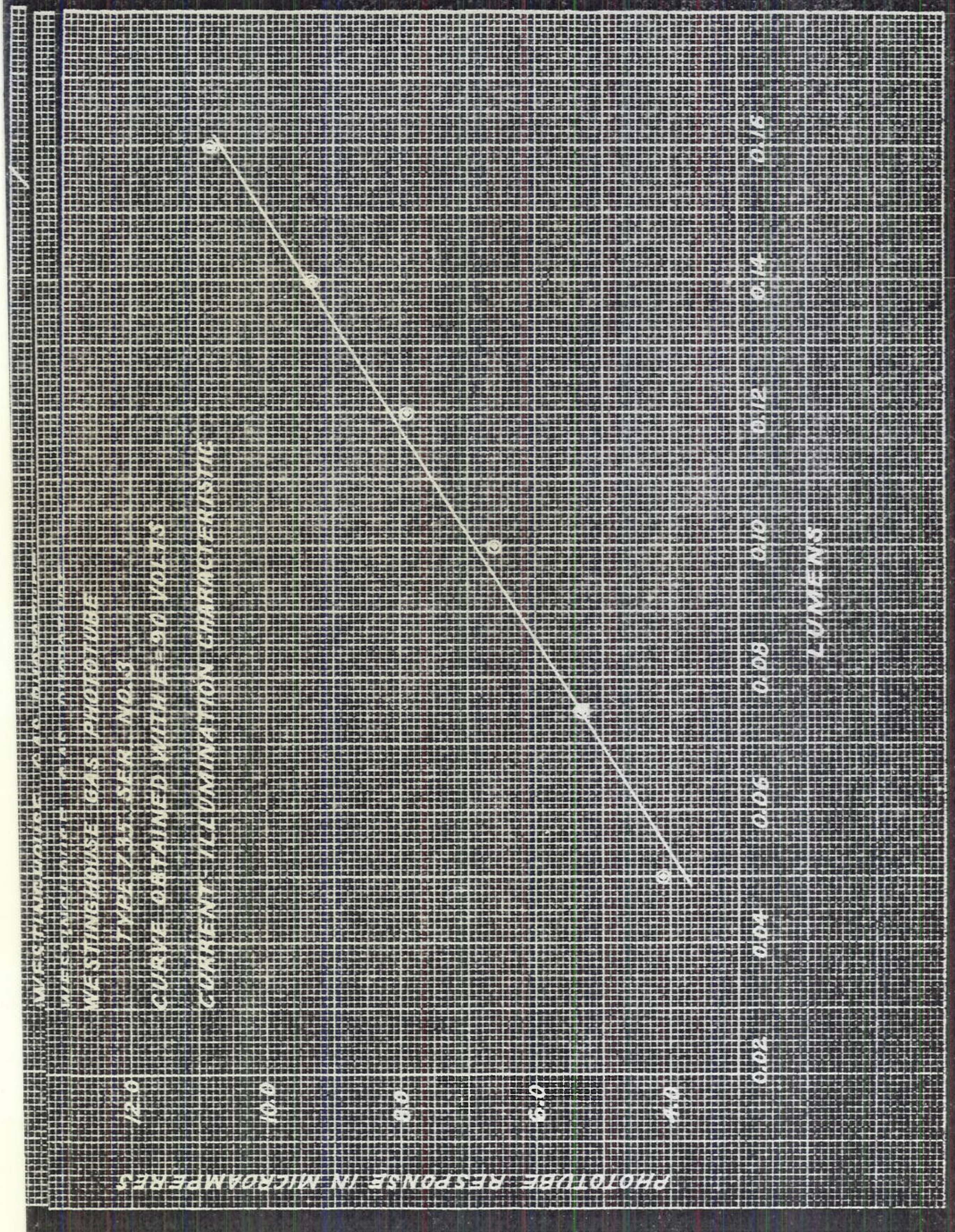

PLATE 15

BELLEVUE, D. C. DATE

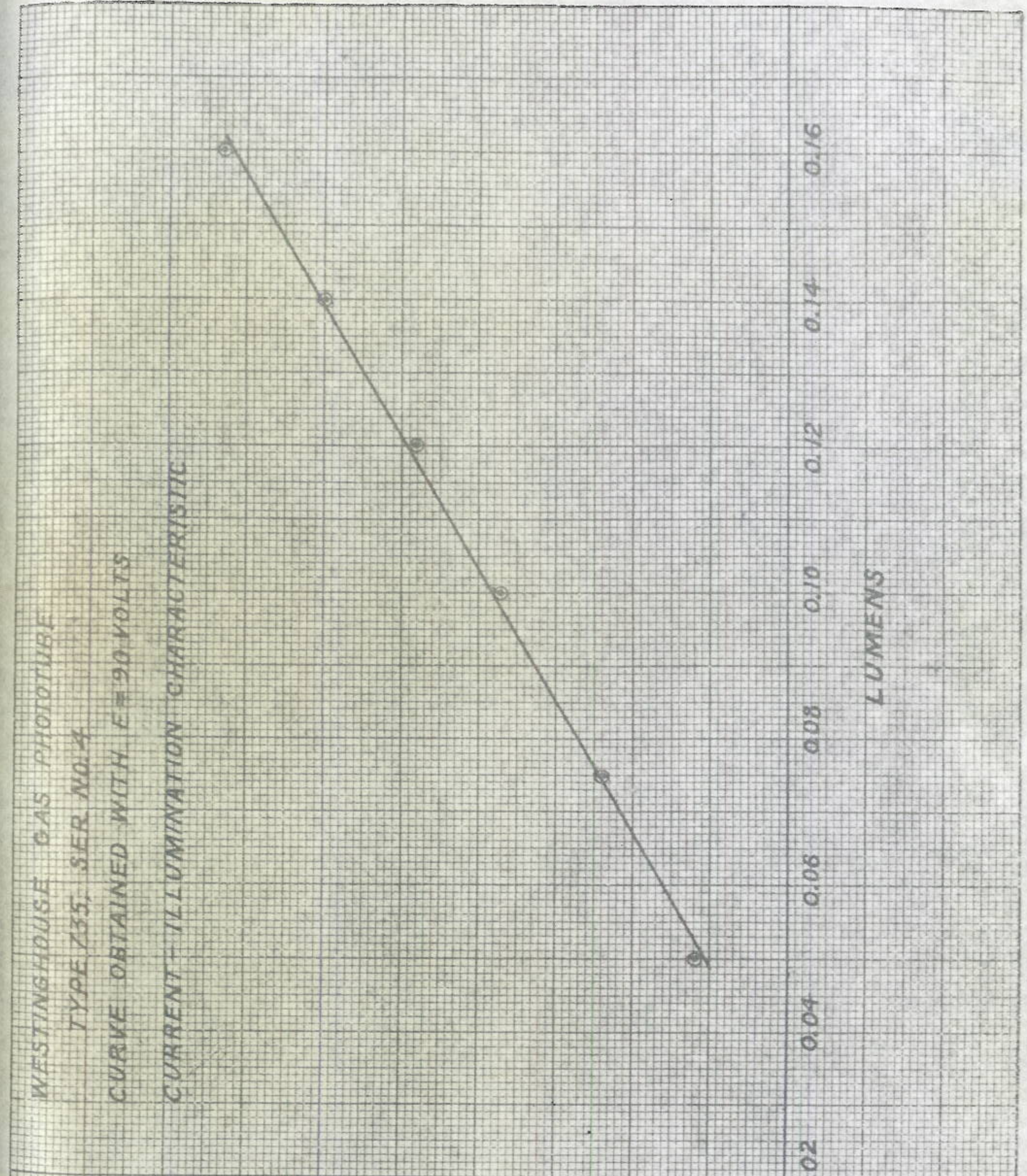

PLATE 16

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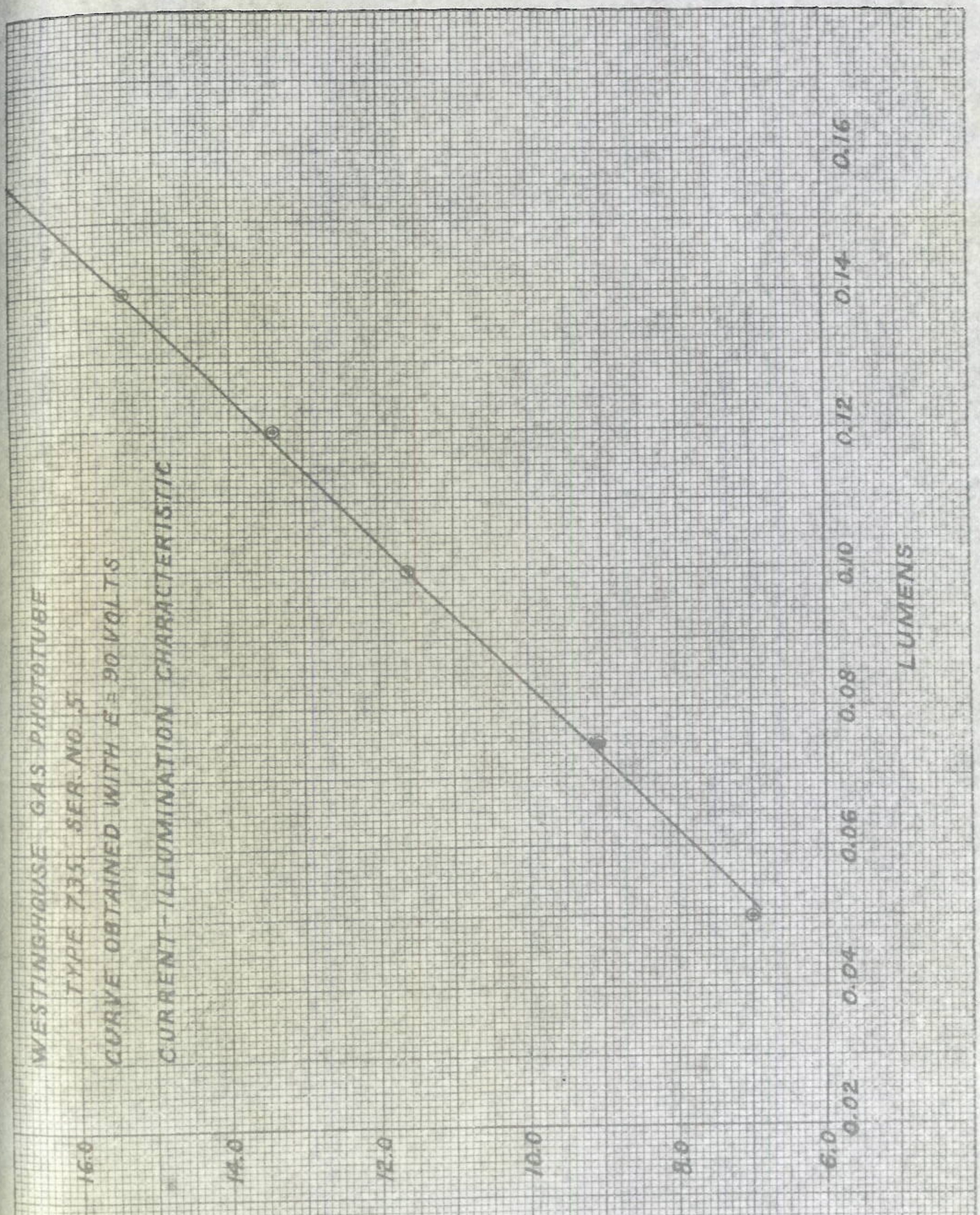

PLATE 17

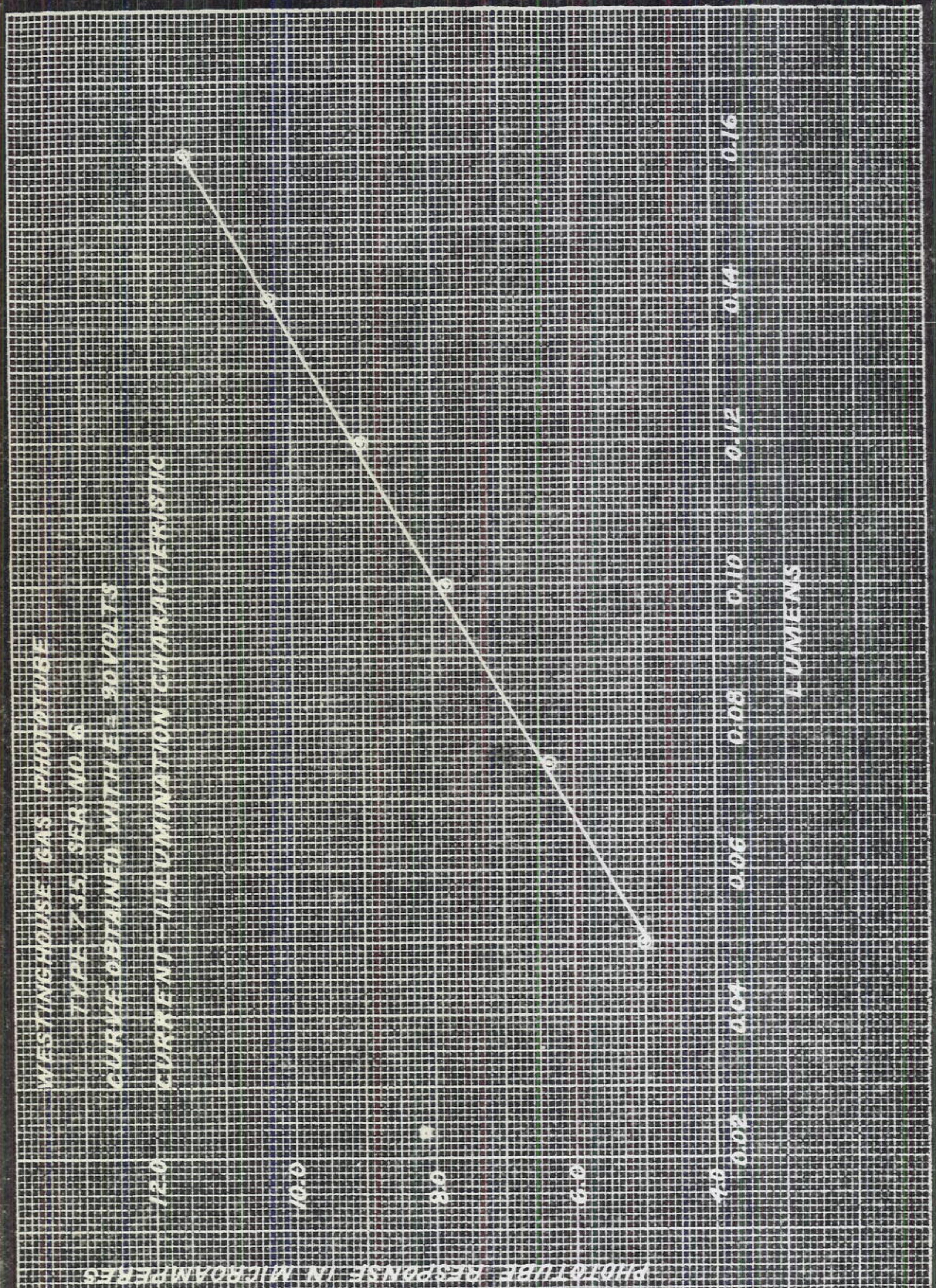
WESTINGHOUSE GAS PHOTOTUBE
TYPE 735 SER. NO. 6
CURVE OBTAINED WITH E = 90 VOLTS
CURRENT ILLUMINATION CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
12.0
10.0
8.0
6.0
4.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
LUMENS

PLATE 18

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

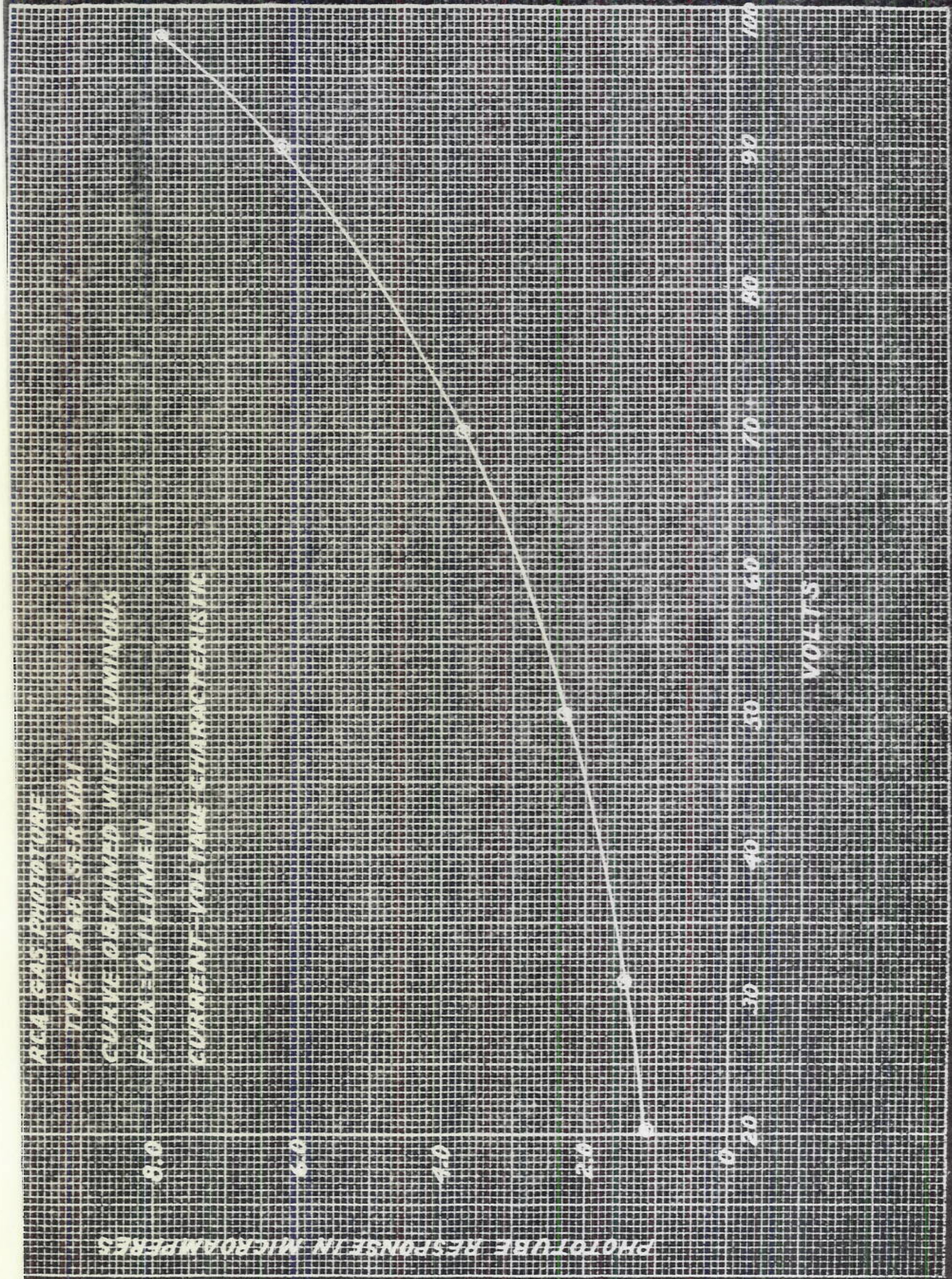

PLATE 19

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DATE

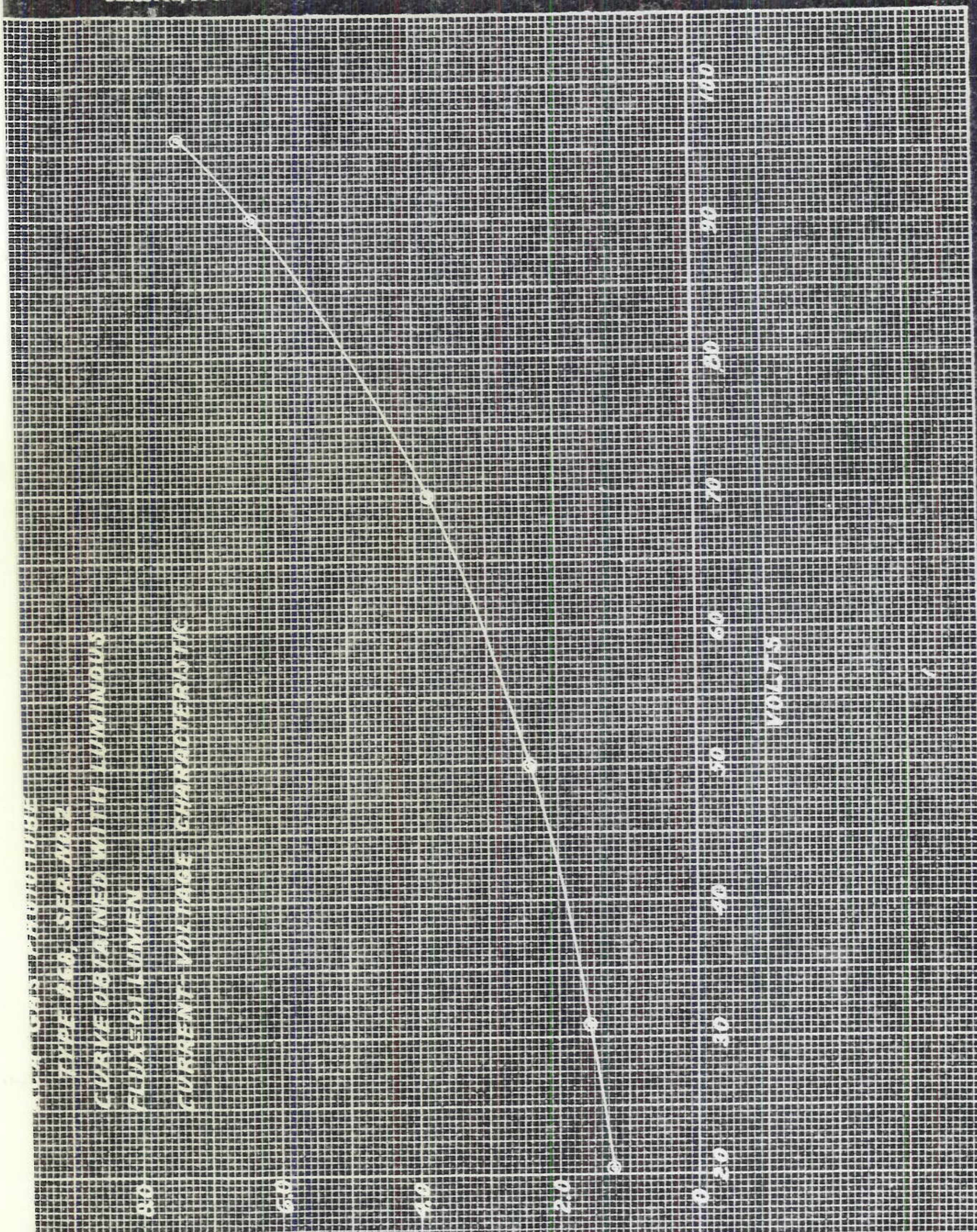

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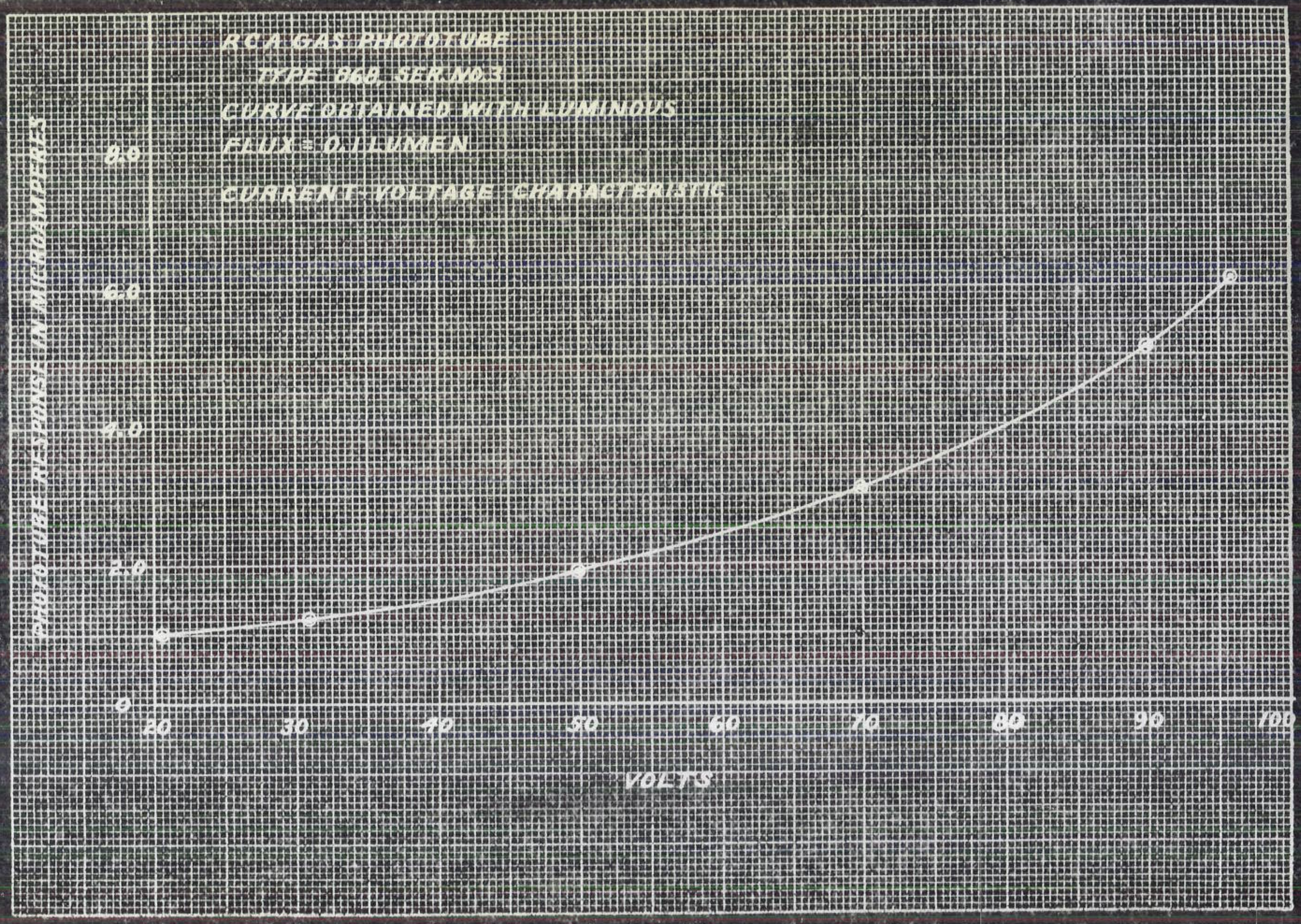
PLATE 20



RCA GAS PHOTOTUBE
TYPE 868, SER.No.3
CURVE OBTAINED WITH LUMINOUS
FLUX = 0.1 LUMEN
CURRENT VOLTAGE CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
8.0
6.0
4.0
2.0
0
20
30
40
50
60
70
80
90
100
VOLTS

PLATE 21

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BELLEVUE, D. C.

DATE

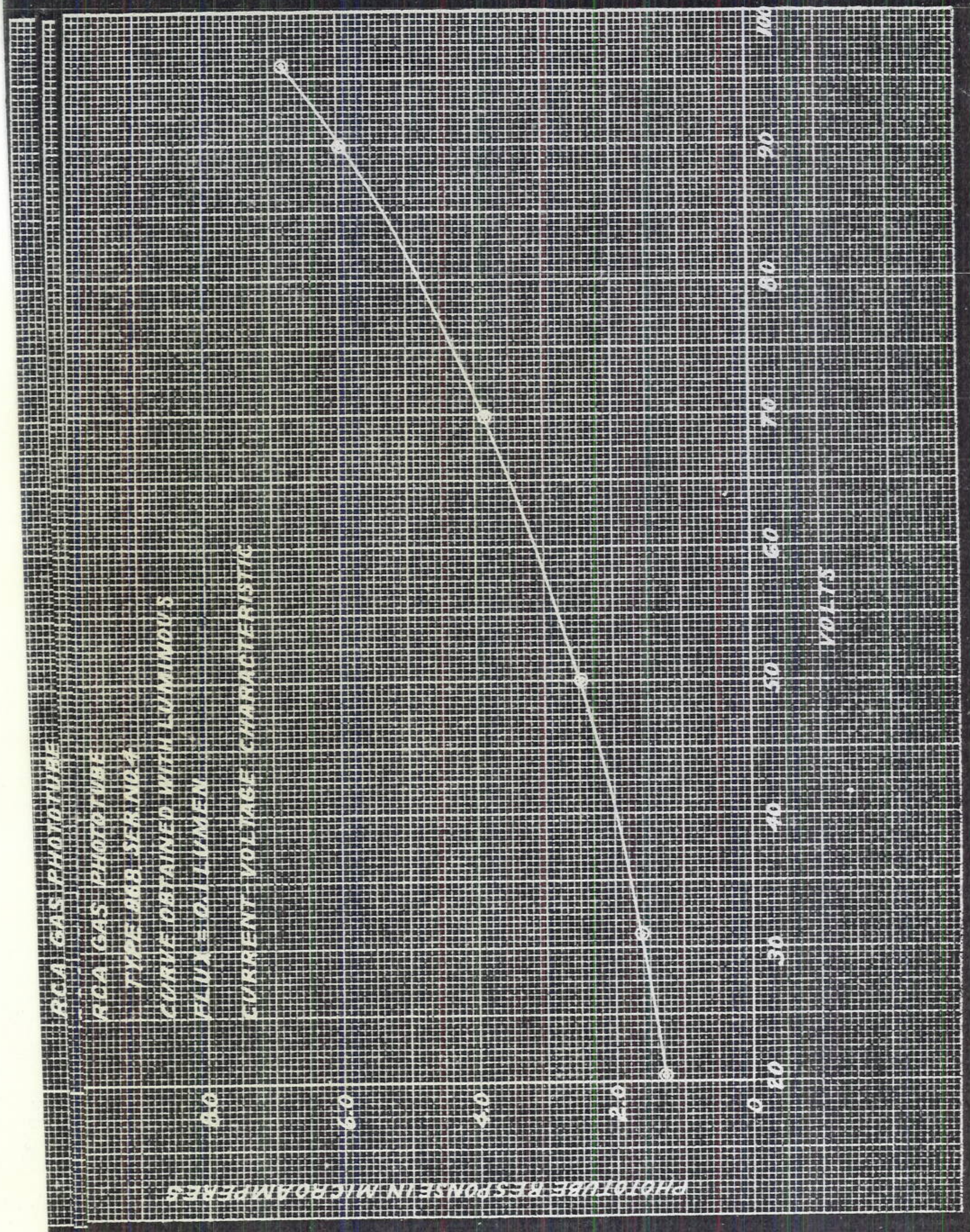


PLATE 22

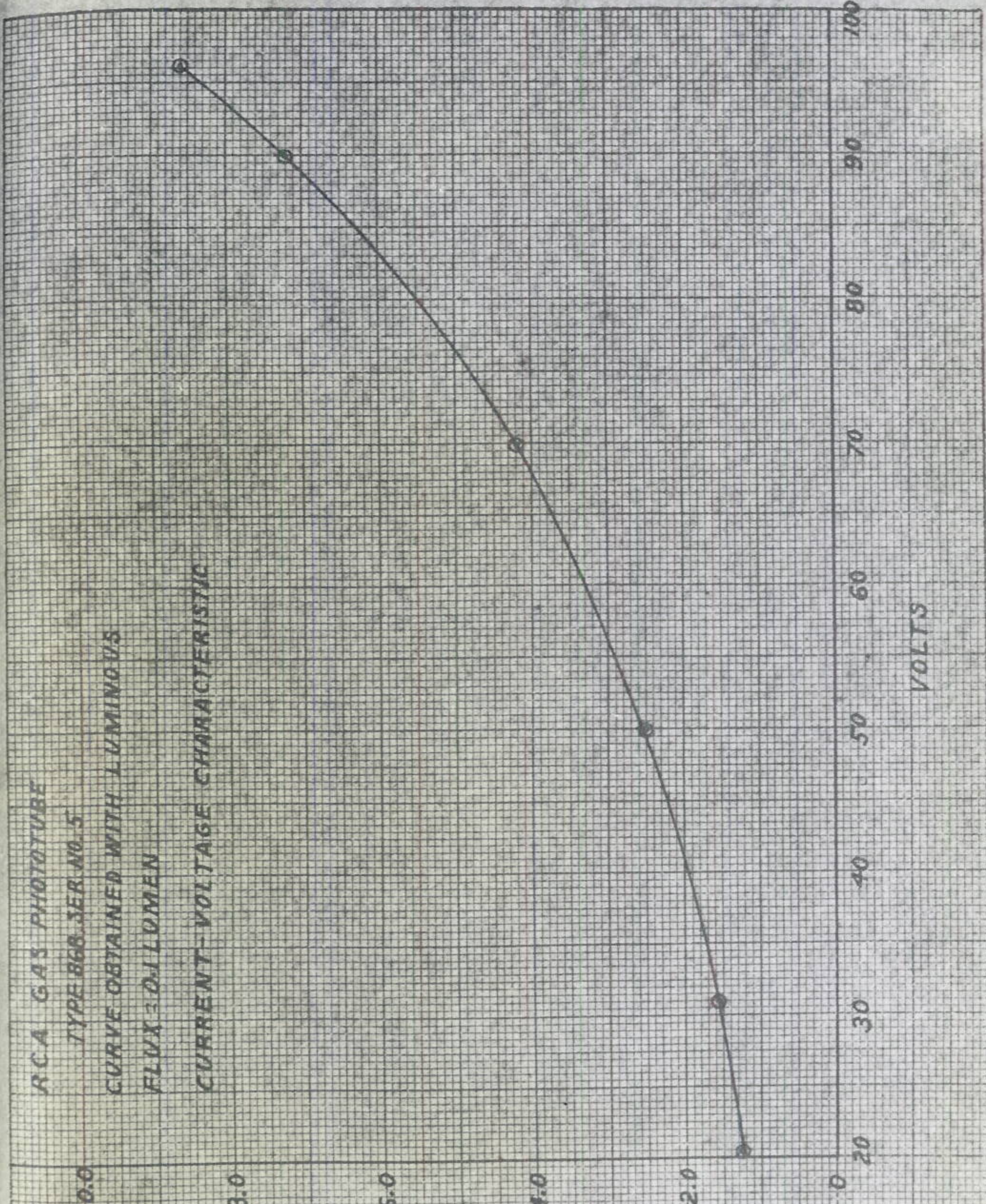

RCA GAS PHOTOTUBE
TYPE 868 SER. NO. 5
CURVE OBTAINED WITH LUMINOUS
FLUX = 0.1 LUMEN
CURRENT-VOLTAGE CHARACTERISTIC
VOLTS
20
30
40
50
60
70
80
90
100
PHOTOTUBE RESPONSE IN MICROAMPERES
0
2.0
4.0
6.0
8.0
10.0

PLATE 23

BELLEVUE, D. C. DATE

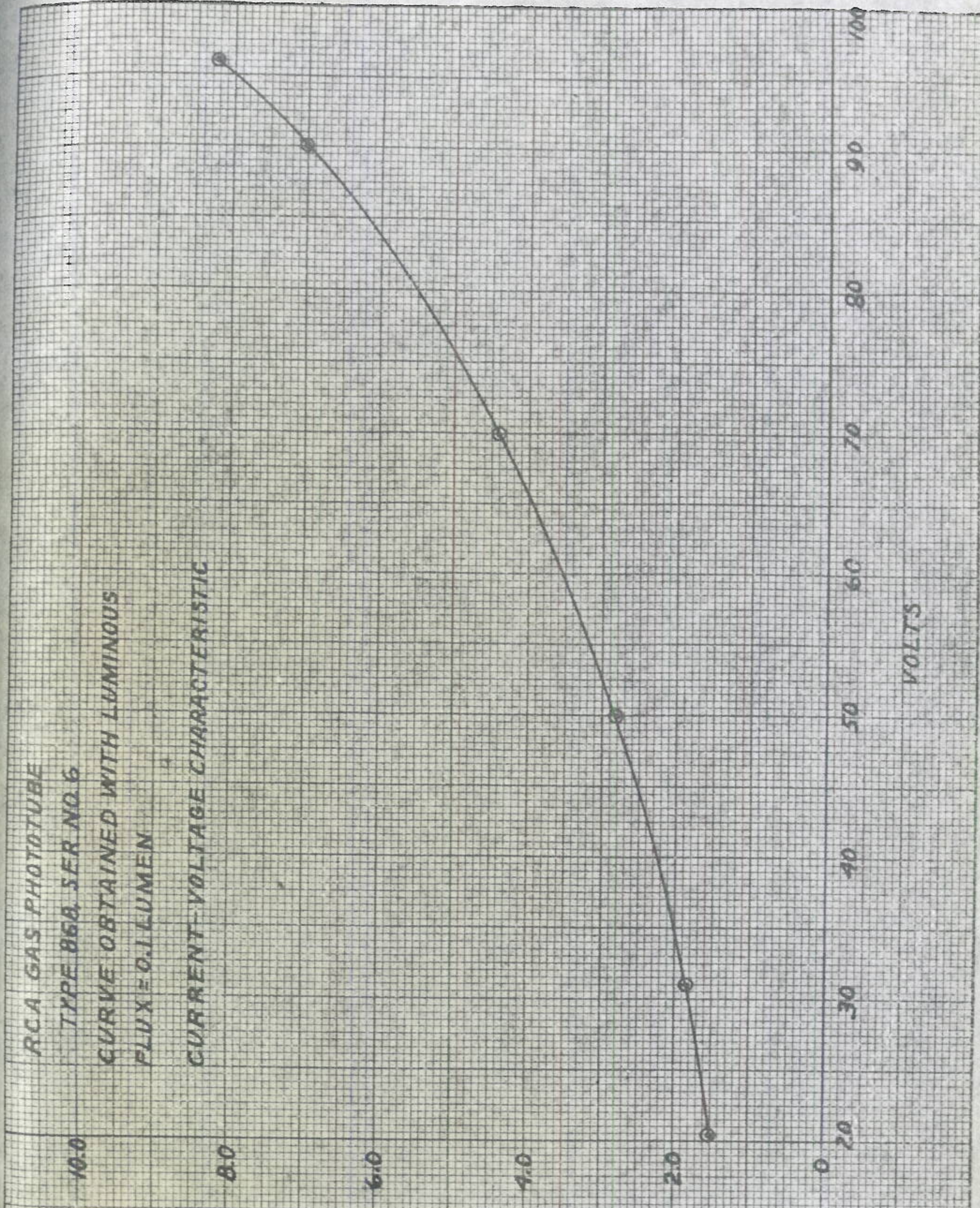


PLATE 24

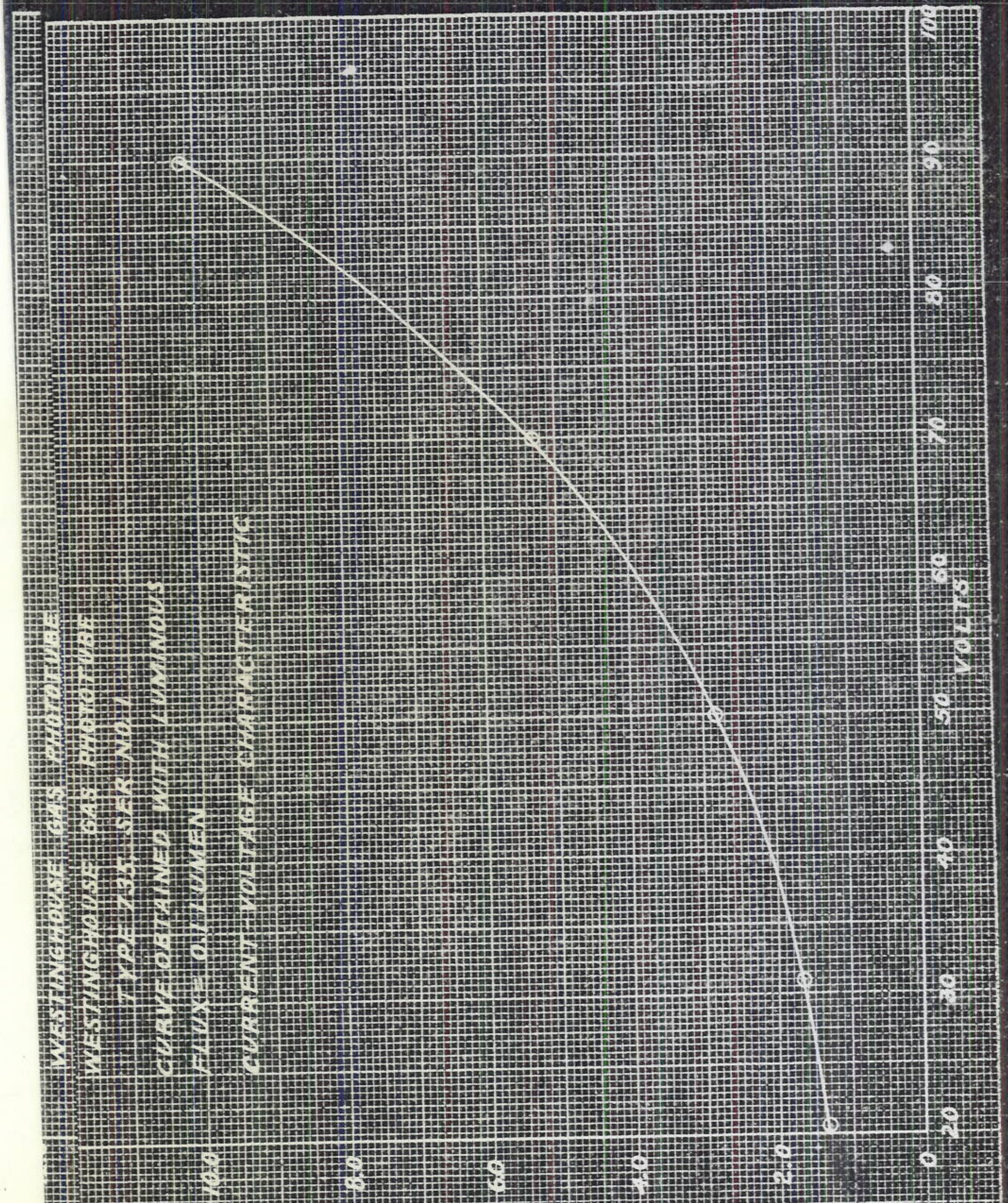
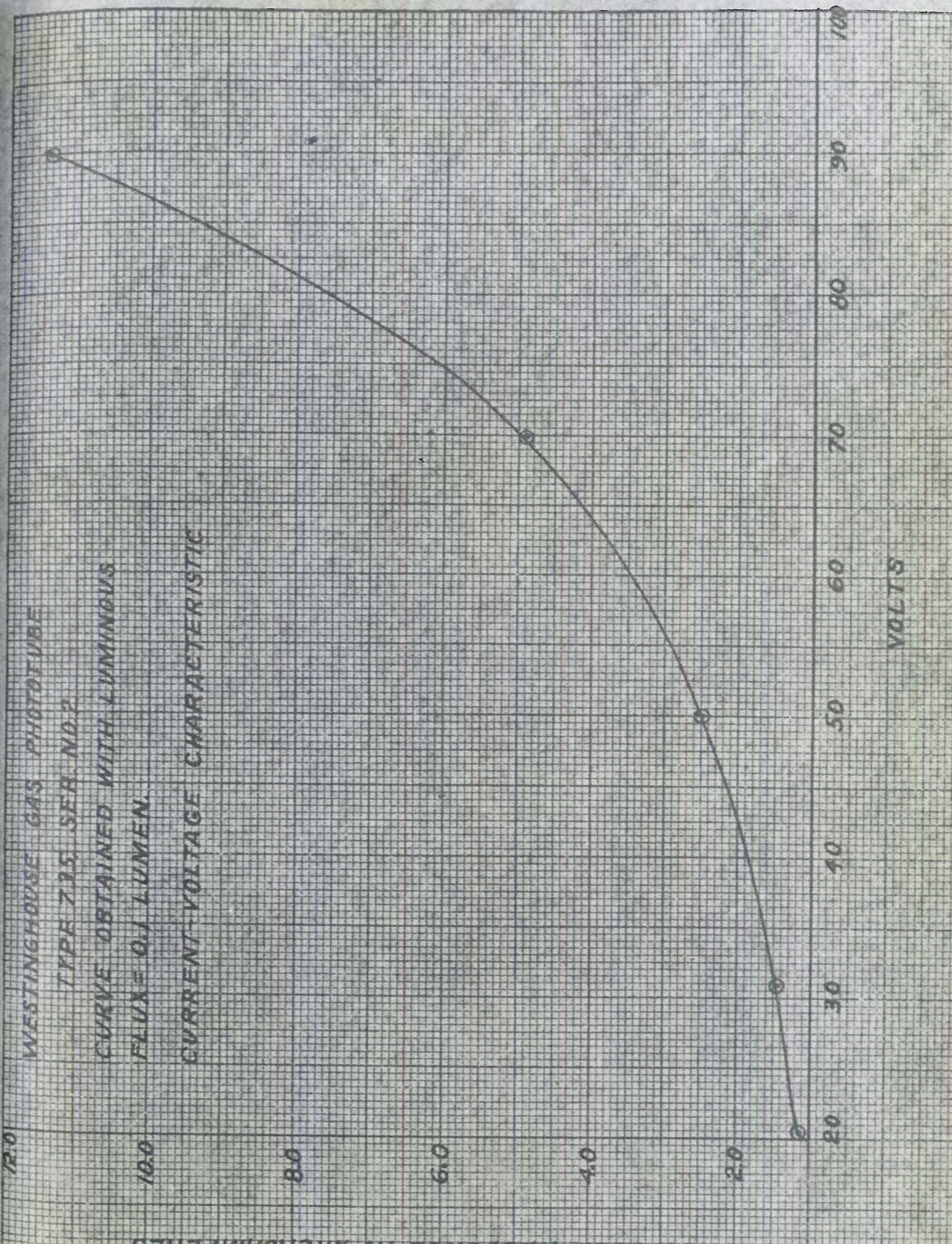

WESTINGHOUSE GAS PHOTOTUBE
WESTINGHOUSE GAS PHOTOTUBE
TYPE 735, SER. NO. 1
CURVE OBTAINED WITH LUMINOUS
FLUX = 0.1 LUMEN
CURRENT VOLTAGE CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
VOLTS
0
2.0
4.0
6.0
8.0
10.0
20
30
40
50
60
70
80
90
100

PLATE 25



1255

PLATE 26

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

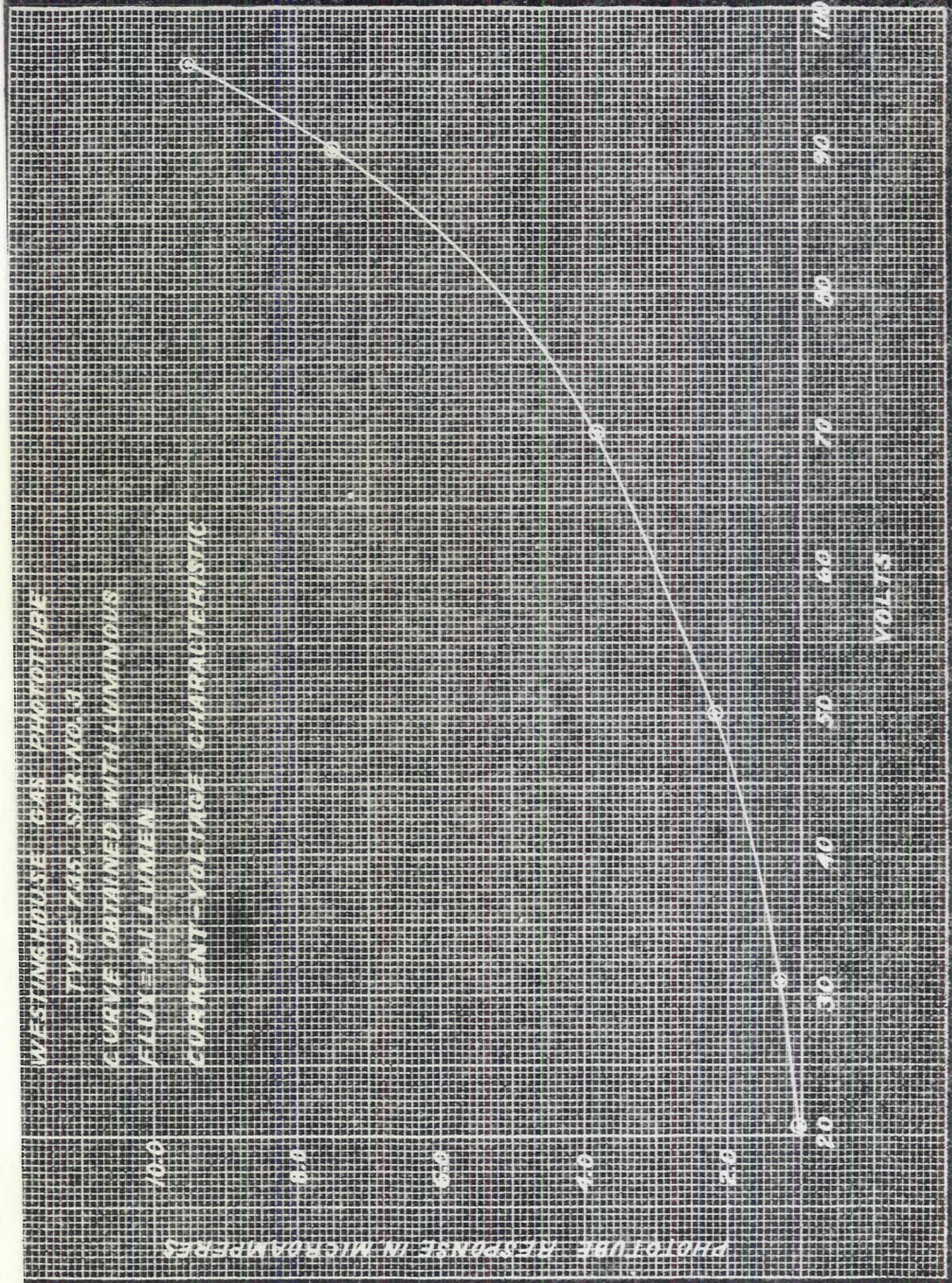


PLATE 27

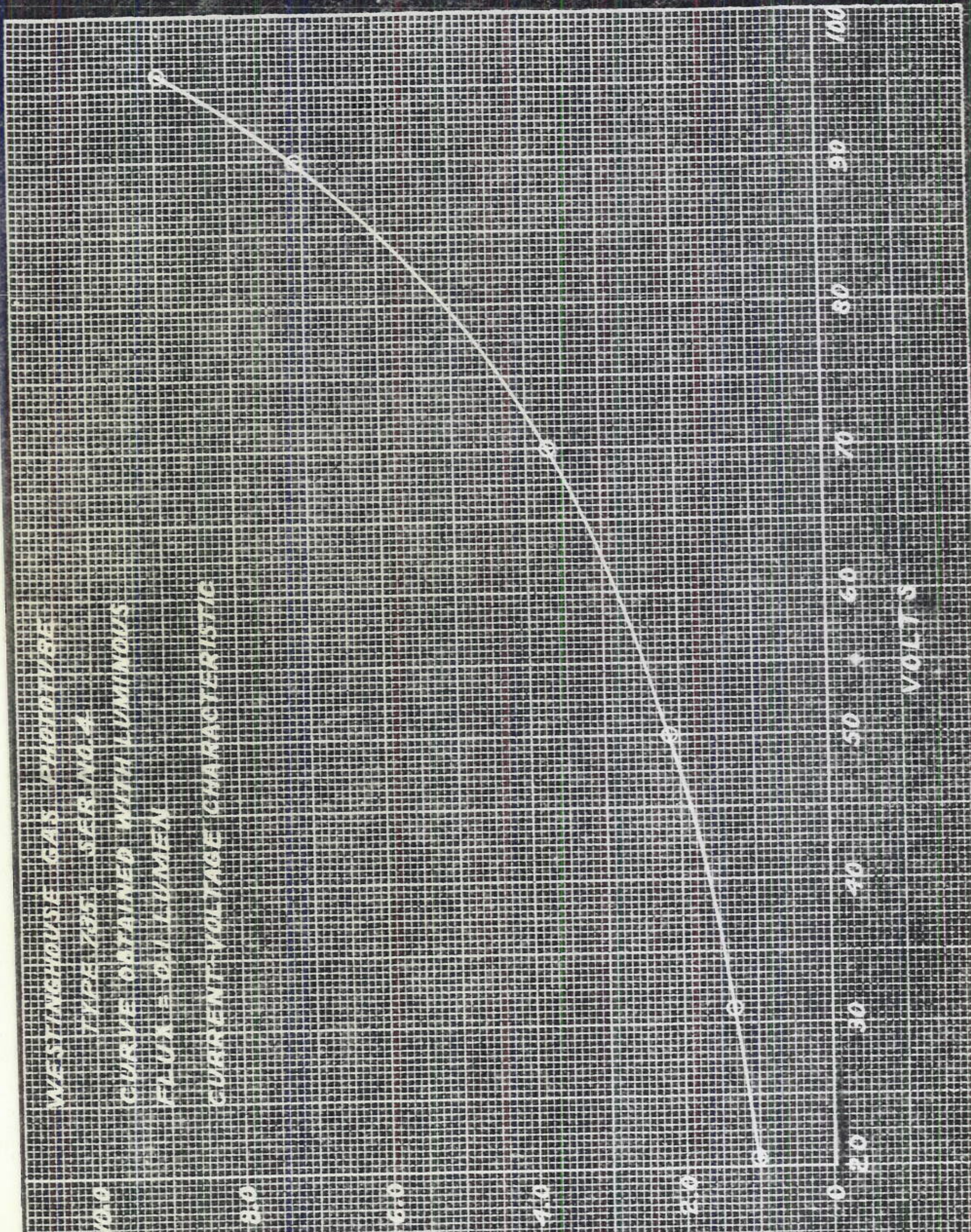
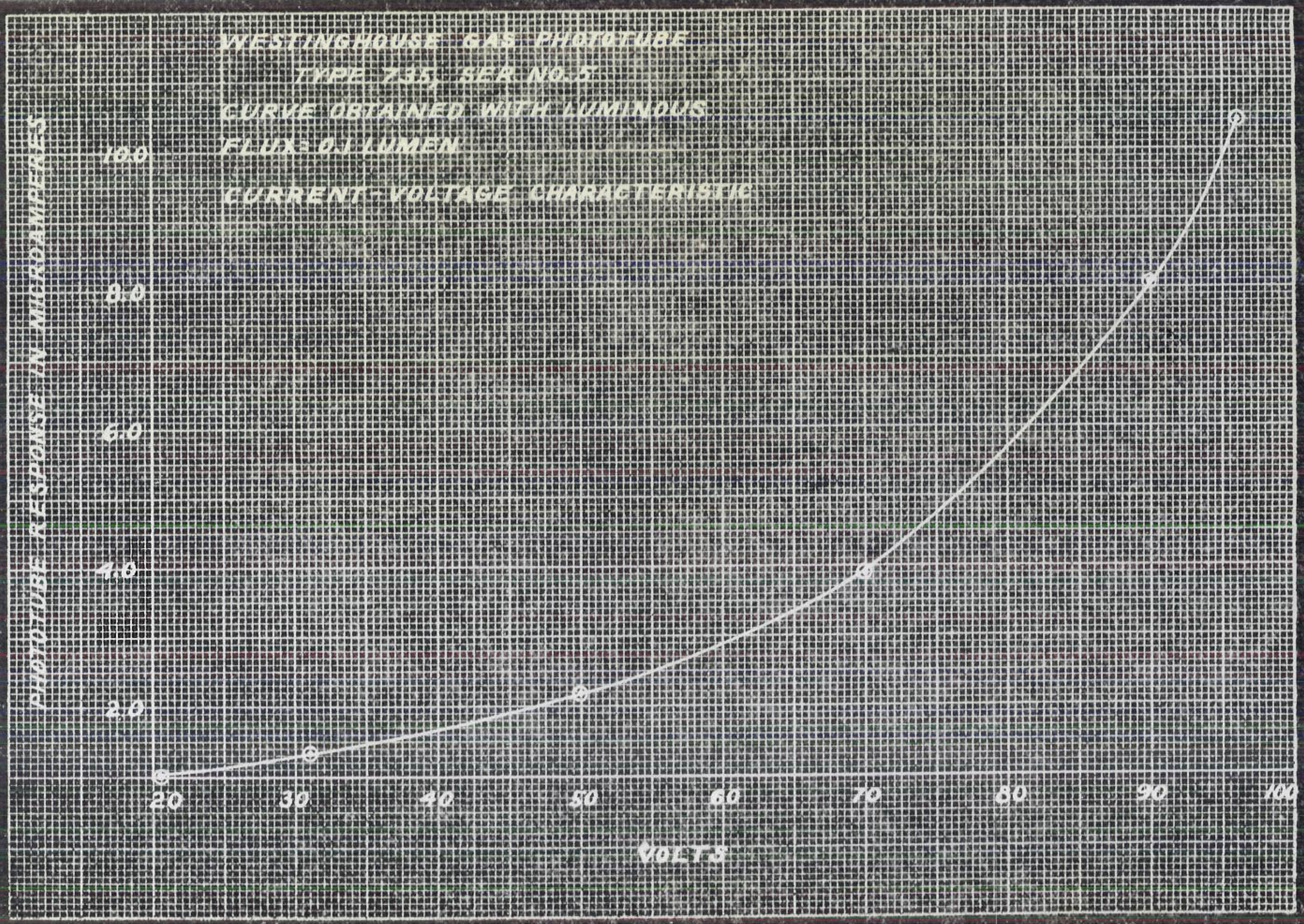

WESTINGHOUSE GAS PHOTOTUBE
TYPE 735 SER. NO. 4
CURVE OBTAINED WITH LUMINOUS
FLUX = 0.1 LUMEN
CURRENT-VOLTAGE CHARACTERISTIC
PHOTOTUBE RESPONSE IN MICROAMPERES
10.0
8.0
6.0
4.0
2.0
0
20
30
40
50
60
70
80
90
100
VOLTS

PLATE 28



BELLEVUE, D.C.

DATE

PLATE 29

BELLEVUE, D. C.

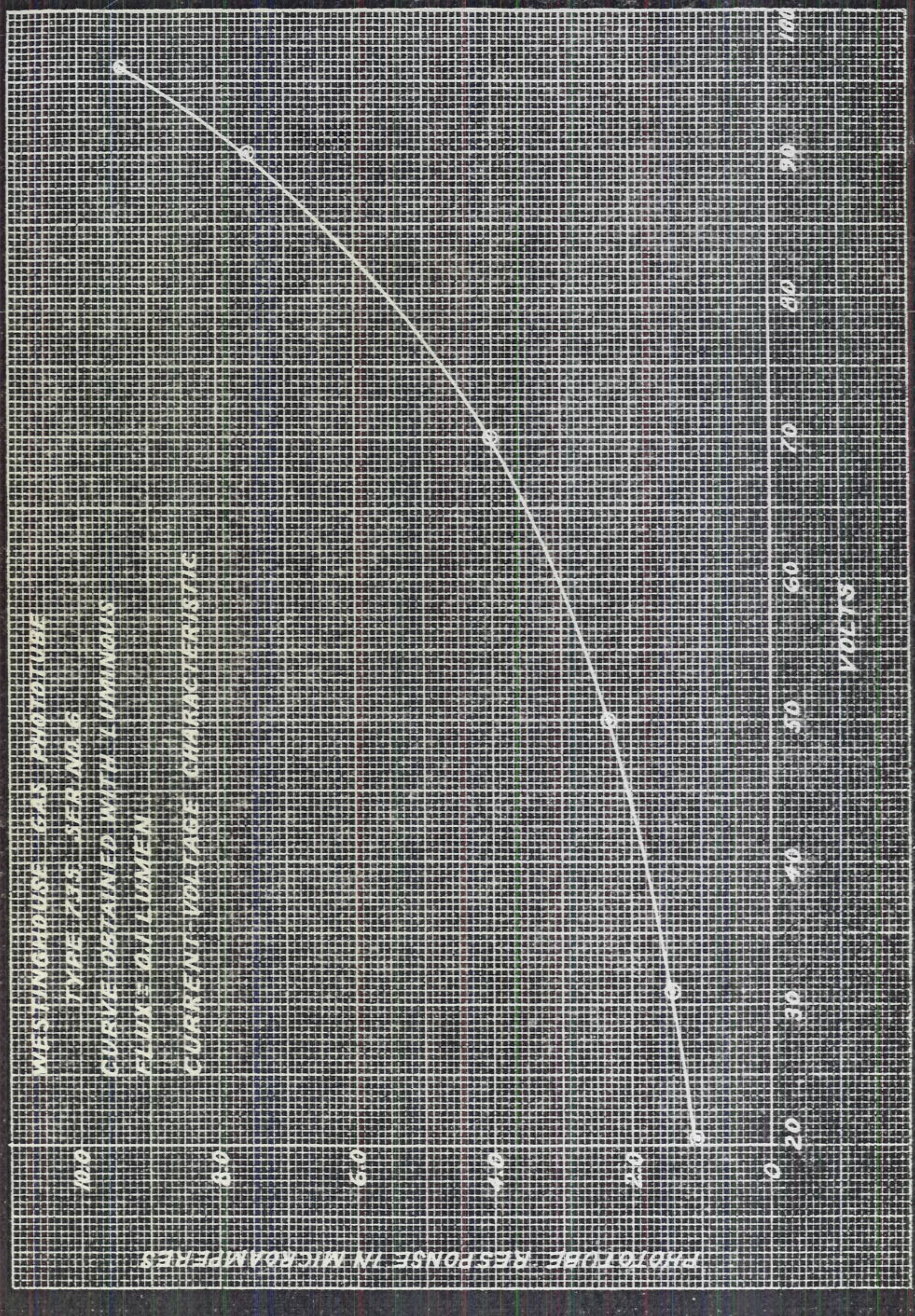


PLATE 30