NATIONAL BUREAU OF STANDARDS REPORT

8392

Approximations of the Effective Intensity

of

PAR-Type Lamps Mounted on a Rotating Turntable

By
G. P. Gillum

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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By
G. P. Gillum
Photometry and Colorimetry Section
Metrology Division

Prepared For
Bureau of Naval Weapons
Department of the Navy
Washington, D.C.

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ABSTRACT

Approximations of the effective intensity of several PAR-type lamps mounted on rotating turntables are given for turntable speeds of 1 to 200 rpm and for all angles of elevation. The lamp types are: 6.6A/PAR56/2, 20A/PAR56, 20A/PAR56Q/1, 20A/PAR56/2, 20A/PAR56Q/3, 200PAR (CC-8 filament), 200PAR (C-13 filament), 300PAR56/NSP, 399PAR, 500PAR64/NSP, 500PAR64/MFL, 200PAR46/3NSP, 4519, and 20A/PAR36/1.

The data for each lamp type are given in a plot of effective intensity factor as a function of turntable speed, and a vertical intensity distribution. The data are intended for engineering design purposes. The errors involved in the approximations are discussed.

1. INTRODUCTION AND BASIC PRINCIPLES

1.1 General

Lights with revolving beams often employ one or more PAR-type lamps mounted on a turntable with a vertical axis of rotation. As steady-burning lamps are rotated, the light appears to flash with a frequency equal to the turntable speed times the number of lamps. The effective intensity is a function of the turntable speed and the intensity distributions, both vertical and horizontal, of the lamps. The signal-lighting engineer is often confronted with such design problems as estimating the effective intensity of a given PAR-type lamp revolving at a stated turntable speed or choosing the turntable speed, lamp type, and number of lamps on the turntable to meet a specified effective intensity distribution and flash rate. Reference data are scant and are not readily available. For example, at the National Bureau of Standards, computations of the effective intensity of PAR-type lamps have been made frequently, but the results are scattered in many reports and are usually limited in scope to one turntable speed and one angle of elevation (for a vertical axis of rotation).

One previous study has been made to develop a simplified method of obtaining the effective intensity of revolving lights.[1] The horizontal intensity

distribution through the peak of the beam, for all lights, is assumed to be approximated by a Gaussian distribution. The distribution is normalized, for each light, by means of a shape factor. By this method, only one curve is necessary to describe the effective intensity factor of all lights at all turntable speeds. However, this method is limited in application since the horizontal distributions through the peak of many PAR-type lamps--for example, prismatic-cover approach-light lamps--are not Gaussian, or close to Gaussian, in shape. Also, the accuracy of this method in approximating the performance of a lamp at angles of elevation some distance from the peak was not investigated.

The purpose of this report is to collect these data in a more useful form and to provide the engineer with a means of obtaining effective intensity distributions of revolving PAR-type lamps with an accuracy sufficient for most engineering design purposes.

1.2 Theory and Method of Computation of Effective Intensity and Effective Intensity Factor

The effective intensity of a flashing light having an instantaneous intensity-time distribution is usually computed, as originally suggested by Blondel and Rey,[2] from the equation

$$I_e = \frac{\int_{t_1}^{t_2} I \, dt}{.2 + (t_2 - t_1)} \tag{1}$$

where

I_e is the effective intensity of the flash,

I is the instantaneous intensity in the increment of time dt,

and

$(t_2 - t_1)$ is a time interval in seconds (less than the whole flash period).

The method for evaluating the expression is given by Douglas.[3] Using this method, the value of $(t_2 - t_1)$ is chosen to maximize I_e. This chosen value is found to be equal to the time interval during which I is equal to or greater than I_e. A planimeter is used to perform the mechanical integration of the area under the instantaneous intensity-time curve between the times t_1 and t_2.

When PAR-type lamps are rotated so as to appear to "flash" to a stationary observer, the instantaneous intensity I, as a function of time, is given by a horizontal intensity-distribution curve through the appropriate angle of elevation. The abscissa must be changed from horizontal

angles in degrees to time in seconds by use of the relation

$$t = \theta/6R \quad (2)$$

where

t is time (in seconds),

θ is the azimuth angle (in degrees) of a point on the intensity-distribution curve, and

R is the speed of rotation (revolutions per minute).

1.3 Effects of Changes in Turntable Speed

For a fixed angle of elevation, the relation between effective intensity and turntable speed is relatively simple. Hence, curves relating effective intensity and turntable speed may be obtained by computing the effective intensity for a few turntable speeds and plotting smooth curves. Effective intensities at other turntable speeds may then be read from these curves.

1.4 Effects of Changes in Angle of Elevation

If the shape of the intensity-time curve of a flashing light does not change with the angle of elevation,* the effective intensity distribution will have the same shape as the instantaneous intensity distribution.

This condition is used to advantage in the photometry of condenser-discharge lights[4] and of incandescent lights which are flashed by switching power to the lamp. In the latter case the effective intensity at any convenient, selected angle of elevation is determined using the methods of reference 3. The ratio of this effective intensity to the steady-burning intensity at the same angle is computed. This ratio can then be applied to the intensities at all other angles of the steady-burning intensity distributions to obtain the effective intensity distributions.

These principles can be applied to lights in which the flash is generated by revolving the lamp when, and only when, the shape of the intensity-time curve is essentially the same for all angles of elevation.

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* The shape of an intensity-time curve is said not to change with the angle of elevation if the ratio of the intensity at the elevation α to the intensity at the elevation β at any time t_a during the flash [t_a corresponding to θ_a by equation (2)] is equal to the ratio of the intensities at any other time t_b during the flash.

If the intensity-time curves have the same shape,

$$I_\alpha = (I_{ref})_\alpha \, f(t) \tag{3}$$

where

I_α is the instantaneous intensity at the time t (azimuth θ) and at any angle of elevation α,

and

$(I_{ref})_\alpha$ is the instantaneous intensity at an arbitrarily selected time (arbitrary azimuth angle θ_{ref}) at the angle of elevation α.

Therefore,

$$(I_e)_\alpha \cong \frac{(I_{ref})_\alpha \int_{t_1}^{t_2} f(t)\, dt}{.2 + (t_2 - t_1)} \tag{4}$$

or

$$(I_e)_\alpha = F\,(I_{ref})_\alpha \tag{5}$$

where

$$F = \frac{\int_{t_1}^{t_2} f(t)\, dt}{.2 + (t_2 - t_1)} \tag{6}$$

F is called the effective intensity factor. Note that, although F does not change with angle of elevation, (for curves of the same shape), F does change with turntable speed since f(t) changes with turntable speed. The value of F for a selected turntable speed is found from equation (5) after computing $(I_e)_\alpha$ for that turntable speed and selected angle of elevation α, and reading $(I_{ref})_\alpha$ from the vertical intensity distribution of the lamp through θ_{ref}. In practice, it has been found convenient and desirable to select the elevation of the peak or of the axis of the beam for α and to select the azimuth of the peak or axis of the beam as the θ_{ref} at which I_{ref} is determined.

As the shape of the intensity-time curve of the beams generated by revolving PAR-type lamps is not usually constant but is a function of the angle of elevation, the results obtained by using the method outlined above are only approximations. One of the purposes of this paper is to determine if the results so obtained are sufficiently accurate for engineering design purposes.

The analysis above has been directed toward a derivation of the effective intensity factor for a particular lamp. In order that the effective intensity factor represent the lamp type, a typical lamp of that type should be used.

2. PROCEDURE

2.1 Lamp Types Studied

The lamp types studied, and a summary of selected characteristics, are shown in table I. The photometric data of the lamps used in this study are taken from various NBS tests. Where data for more than one lamp were available, the data for the lamp believed most representative of the group were used.

2.2 Computational Procedure

The effective intensity factor, F, as defined in equation (6), is a function of the shape of the intensity distribution from which it is derived and of the turntable speed. The functional relationship is complex and varies considerably from lamp type to lamp type. For this reason, the procedure followed in this study is to use equation (5) to calculate the effective intensity factor for several turntable speeds for a selected lamp and plot a curve of F as a function of turntable speed. In this study, a horizontal intensity distribution through the peak of the beam of the lamp is used in the computation of the values of F.

The choice of azimuth angle θ_{ref} was limited by the availability of data. However, in every instance but one, it was possible to choose θ_{ref} as the beam axis or as a point an insignificant distance from the axis. For the one exception, the type 200PAR46/3NSP lamp, the beam axis did not coincide with the major peak. The peak was chosen as θ_{ref}.

Four turntable speeds, 1, 8, 40, and 200 rpm, were found to be sufficient for the construction of the curves of F as a function of turntable speed for turntable speeds in the range of 1 to 200 rpm.

3. RESULTS AND DISCUSSION

3.1 Results

Effective intensity factors as a function of turntable speed for the lamp types examined in this study are shown in figures 1 and 2. Vertical intensity distributions taken from the appropriate NBS tests are shown for each lamp type in figures 3 through 16.

The effective intensity factor for the type 200PAR46/3NSP lamp is not plotted below a turntable speed of 8 rpm (except for the single point at 1 rpm) because of a discontinuity in the curve. The exact position and magnitude of the discontinuity changes from lamp to lamp and thus cannot be predicted. The discontinuity is a result of the presence of two minor peaks in addition to the major peak in the horizontal intensity distribution. In the region of these peaks, the beam width decreases abruptly as the steady-burning intensity increases. This abrupt decrease is reflected in a similarly abrupt change in the effective intensity as the turntable speed is reduced.

TABLE I

Selected Characteristics of the PAR-Lamp Types Studied
(From "Engineering Data on General Electric PAR Lamps;
Revised November, 1962")

Lamp Type	Power (Watts)	Design Volts or Amperes	Filament Form	Approximate Initial Peak Intensity (Candelas)	Beam width at 10% of Peak Intensity Horizontal (Degrees)	Vertical (Degrees)	Pertinent NBS Reports
4519	100	13 V	C-6	30,000	40	7	21P-37/58
20A/PAR36/1	100	20 A	C-6	90,000	9	7	21P-17/58
200PAR46/3NSP	200	120 V	CC-13	36,000[1]	23	17	Memo Report of 8-9-61
6.6A/PAR56/2	200	6.6 A	CC-6	13,500	45	20	21P-3/56
20A/PAR56	300	20 A	C-6	28,000	50	20	21P-4/61
20A/PAR56Q/1	500	20 A	CC-6	47,000	60	20	21P-44/62
20A/PAR56/2	300	20 A	C-6	250,000	20	8	21P-4/61
20A/PAR56Q/3	499	20 A	CC-6	355,000	15	11	21P-44/62
200PAR	200	30 V	CC-8	300,000	9	9	6862
200PAR	200	30 V	C-13	200,000[2]	12[2]	9[2]	6862
300PAR56/NSP	300	120 V	CC-13	70,000[1]	20	15	5905
399PAR	399	115 V	CC-13	30,000	50	20	21P-6/54
500PAR64/NSP	500	120 V	CC-13	104,000[1]	20	13	21P-46/60
500PAR64/MFL	500	120 V	CC-13	35,000	35	20	21P-46/60

[1] Approximate mean initial intensity in 5° cone.

[2] From "Engineering Data on PAR Lamps; Revised June 1, 1956" by the General Electric Company.

3.2 Method of Approximating Effective Intensity

The use of these curves to obtain effective intensity is simple and straightforward. After a lamp type and a turntable speed are chosen, an effective intensity factor is obtained from figure 1 or 2, as applicable. Reference is then made to the appropriate vertical intensity distribution. For any selected elevation angle, the effective intensity is the intensity at that angle multiplied by the effective intensity factor. As an obvious extension of the above computation, the effective intensity distribution is found by multiplying each point on the vertical intensity distribution by the effective intensity factor.

3.3 Sources of Error

The two principal sources of error in application of the data and of the method for the approximation of effective intensity presented in this paper are: First, the lamps used are not necessarily typical of their respective lamp types and are certainly not representative of all lamps within their respective lamp types. The magnitude of the resultant error cannot be determined. The principal portion of this error is caused by manufacturing variations, such as filament placement, which usually produce greater changes in the vertical intensity distributions than in the effective intensity factors. The second source of error lies in the assumption that all horizontal intensity distributions of a lamp are of the same shape. The error resulting from this assumption is a function of turntable speed, angle of elevation, and lamp type. The error was found to be a maximum for turntable speeds between 40 and 80 rpm.

An investigation was made into the effects of angle of elevation and of lamp type on the error. Several lamp types from the group were selected in order to include as many varieties of beam shapes as possible. The investigation was limited to angles of elevation where the intensity was above about 20% of the peak intensity. Data from five of the lamp types investigated are shown in table II. The error that results from assuming F to be constant (at a turntable speed of 40 rpm) over all angles of elevation is given in the last column of the table. The two lamps that were found to have the greatest errors, the type 200PAR lamp (CC-8 filament) and the type 200PAR46/3NSP lamp, are included in the table. If these two lamp types are excluded, the maximum error is less than 20% for all lamp types examined at all angles of elevation examined. It is believed that this 20% maximum error would apply to the other lamp types included in this paper but not in the investigation of the effects of angle of elevation and lamp type on the error.

It is evident from table II that there is a rough correlation between the displacement of the angle of elevation from the peak and the error. Thus, for the angles of elevation of greatest interest, those within 2° of the peak, the error is considerably less than 20%. Also, at the larger displacements of the angle of elevation, the effective intensity found by use of the effective intensity factor is usually lower than the actual value (obtained by direct computation).

TABLE II

Variation of the Effective Intensity Factor with Angle of Elevation for Several of the Lamp Types Studied (at a turntable speed of 40 rpm)

Lamp Type	Angle of Elevation (Degrees)	Maximum Instantaneous Intensity, as a Percentage of Peak Instantaneous Intensity	Effective Intensity Factor F	Relative Values of F[2]	Percent Error Originating in Assumption that F is constant[3]
4519	- 2	28	.320	118	- 18
	- 1	61	.296	109	- 9
	0	95	.279	103	- 3
	1[1]	100	.272	100	0
	2	65	.270	99	1
	3	23	.307	113	- 13
20A/PAR36/1	- 2	42	.084	88	12
	- 1	91	.087	91	9
	0[1]	100	.095	100	0
	1	98	.092	97	3
	2	62	.087	92	8
	3	19	.098	103	- 3
200PAR (CC-8 filament)	- 4	21	.119	147	- 47
	- 3	33	.111	137	- 37
	- 2	61	.093	115	- 15
	- 1	92	.081	99	1
	0[1]	100	.081	100	0
	1	88	.078	97	3
	2	63	.082	102	- 2
	3	38	.095	117	- 17
	4	22	.104	128	- 28

200PAR (G-13 filament)	- 4	19	.112	116	- 16
	- 3	41	.107	111	- 11
	- 2	72	.107	110	- 10
	- 1	98	.101	105	- 5
	0 (1)	100	.097	100	0
	1	71	.098	102	- 2
	2	45	.102	106	- 6
	3	25	.095	99	1
	4	10	.100	104	- 4
200PAR46/3NSP	- 6	22	.187	113	- 13
	- 4	33	.210	127	- 27
	- 2	52	.210	127	- 27
	1 (1)	100	.165	100	0
	2	90	.172	105	- 5
	4	55	.206	125	- 25
	6	33	.206	125	- 25

(1) Angle of elevation used in obtaining F for figure 1 or 2.

(2) Relative values are based on the value for F entered, for the lamp type, in figure 1 or 2.

(3) Percent error in the approximated effective intensity arising from the use of the value of F, found in figure 1 or 2 (for the lamp type). A negative error corresponds to an underapproximation of the effective intensity.

The cause of the significantly larger error encountered with the type 200PAR lamp (CC-8 filament) has not been determined. A possible cause is the circular shape of the beam, but no correlation between beam shape and error has been found for the other lamps investigated.

The large error encountered with the type 200PAR46/3NSP lamp can be explained. The shape of the horizontal intensity distribution changes radically with the angle of elevation (see figure 17) from that described in Section 3.1 to a smooth, almost square-shaped beam at ± 4°.

3.4 Applicability of Method

This method of obtaining effective intensity distributions is considered adequate for engineering design purposes where PAR-type lamps are to be used in revolving lights. Use of this method makes possible the easy and compact grouping of data for many lamp types and many turntable speeds for reference use.

Estimated effective intensity factors for lamp types which are not included in this report may be obtained with an accuracy sufficient for many preliminary engineering purposes by comparing the shape of distribution curves, both vertical and horizontal, of a selected lamp type with the intensity distributions of those for which the effective intensity factor is plotted on figures 1 and 2 and estimating the effective intensity factor from the appropriate curve. A vertical intensity distribution through the beam axis of the selected lamp should be used to obtain the estimated effective intensity unless the vertical distribution of the selected lamp is somewhat skewed (as was that of the type 200PAR46/3NSP lamp). In the latter case, a vertical intensity distribution through the peak should be used.

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1. M. R. Wohlers and H. A. Leupp, Ill. Eng. 54, 412 (1959).

2. A. Blondel and J. Rey, Journal de Physique 1 (5th Series), 643 (1911).

3. C. A. Douglas, Ill. Eng. 52, 641 (1957).

4. C. A. Douglas, Ill. Eng. 53, 205 (1958).

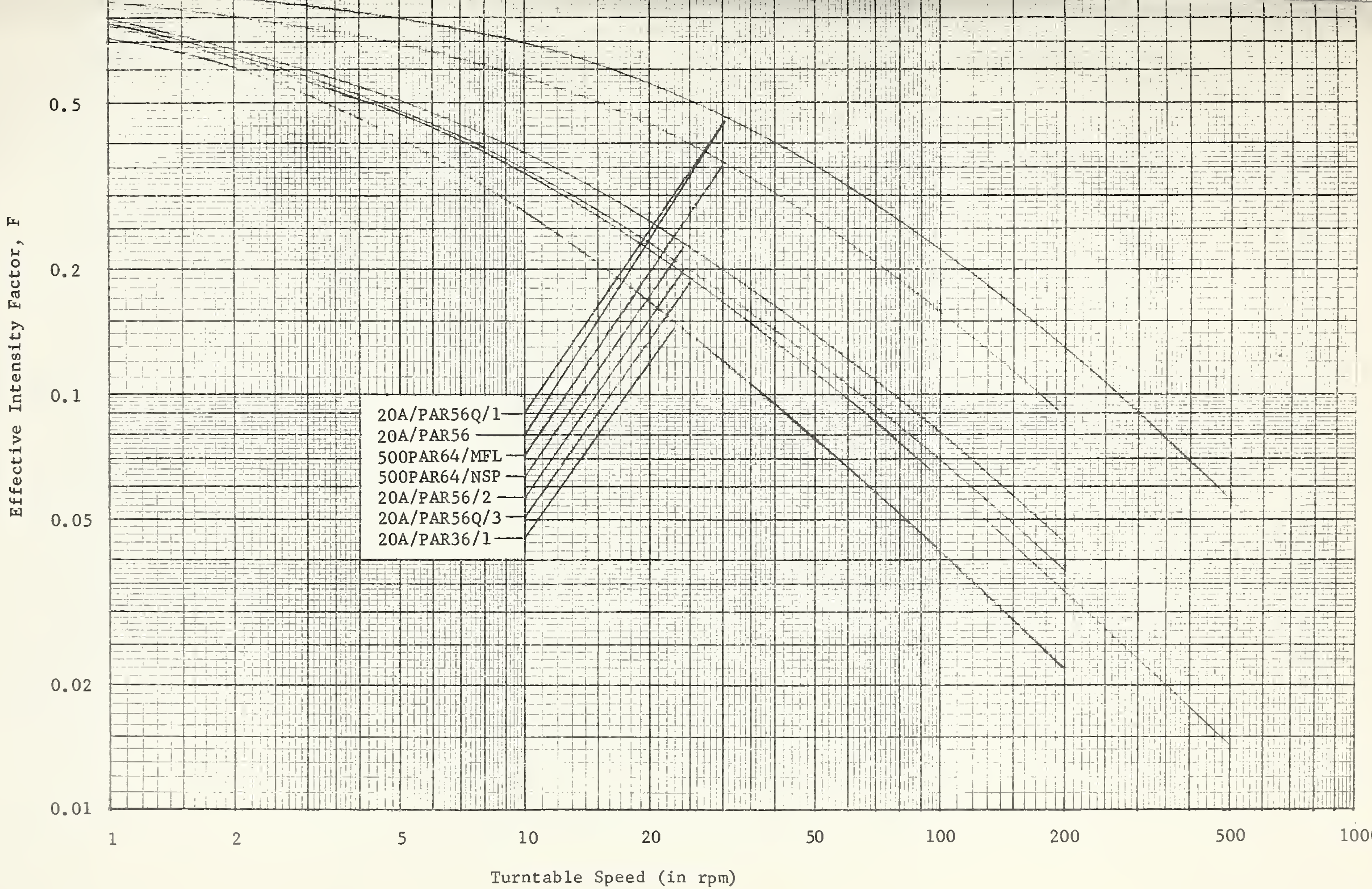

Figure 1. Effective intensity factor as a function of turntable speed for several PAR-type lamps. The effective intensity of a lamp at a given angle of elevation and turntable speed is equal to the product of the effective intensity factor at that turntable speed and the intensity at that angle of elevation given by the appropriate accompanying intensity distribution.

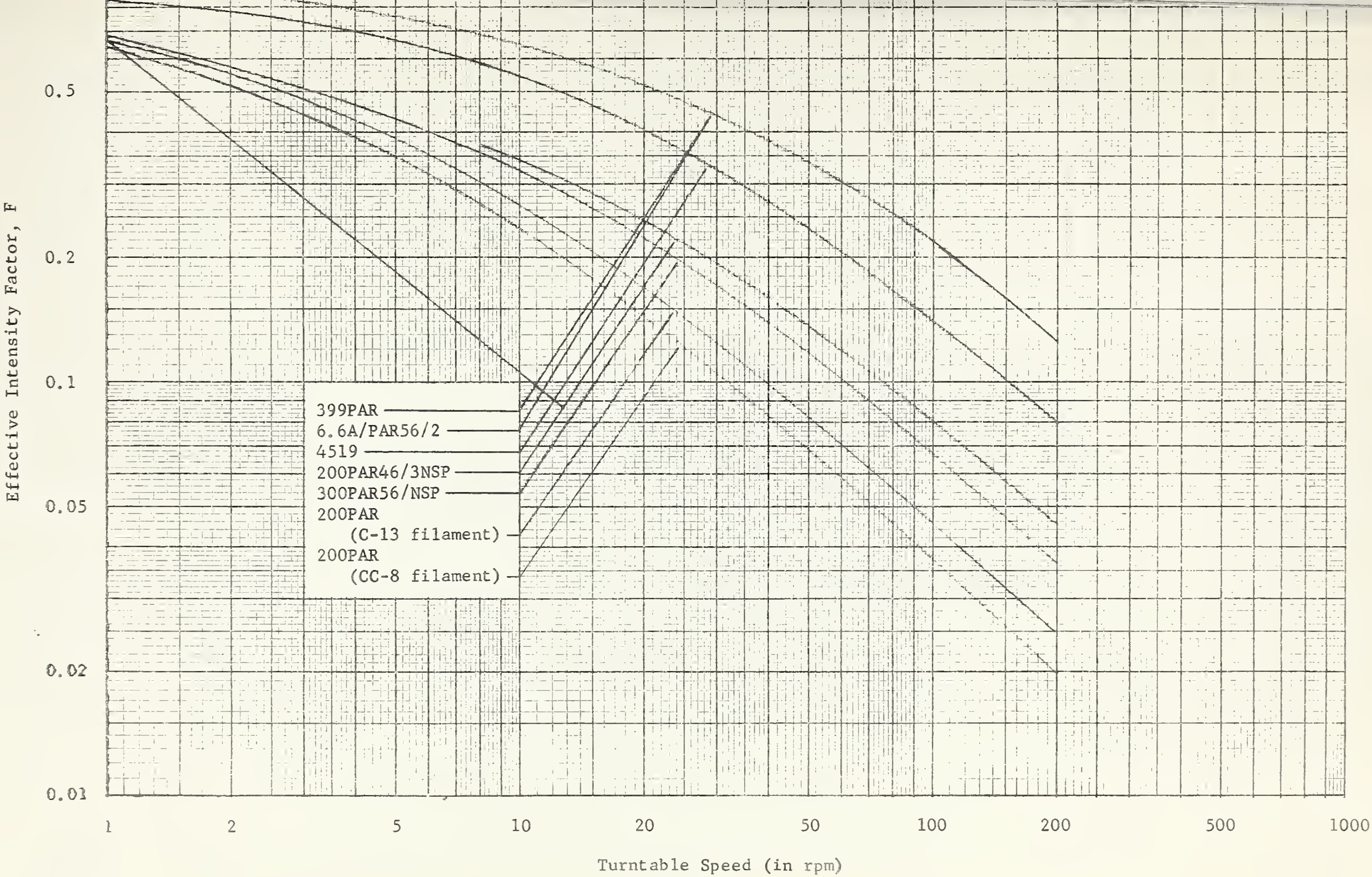

Figure 2. Effective intensity factor as a function of turntable speed for several PAR-type lamps. The effective intensity of a lamp at a given angle of elevation and turntable speed is equal to the product of the effective intensity factor at that turntable speed and the intensity at that angle of elevation given by the appropriate accompanying intensity distribution.

Vertical Intensity Distribution

of a

Type 20A/PAR56 Lamp

(Lamp No. 2 from NBS Test 21P-4/61)

operated at rated current of 20 amperes

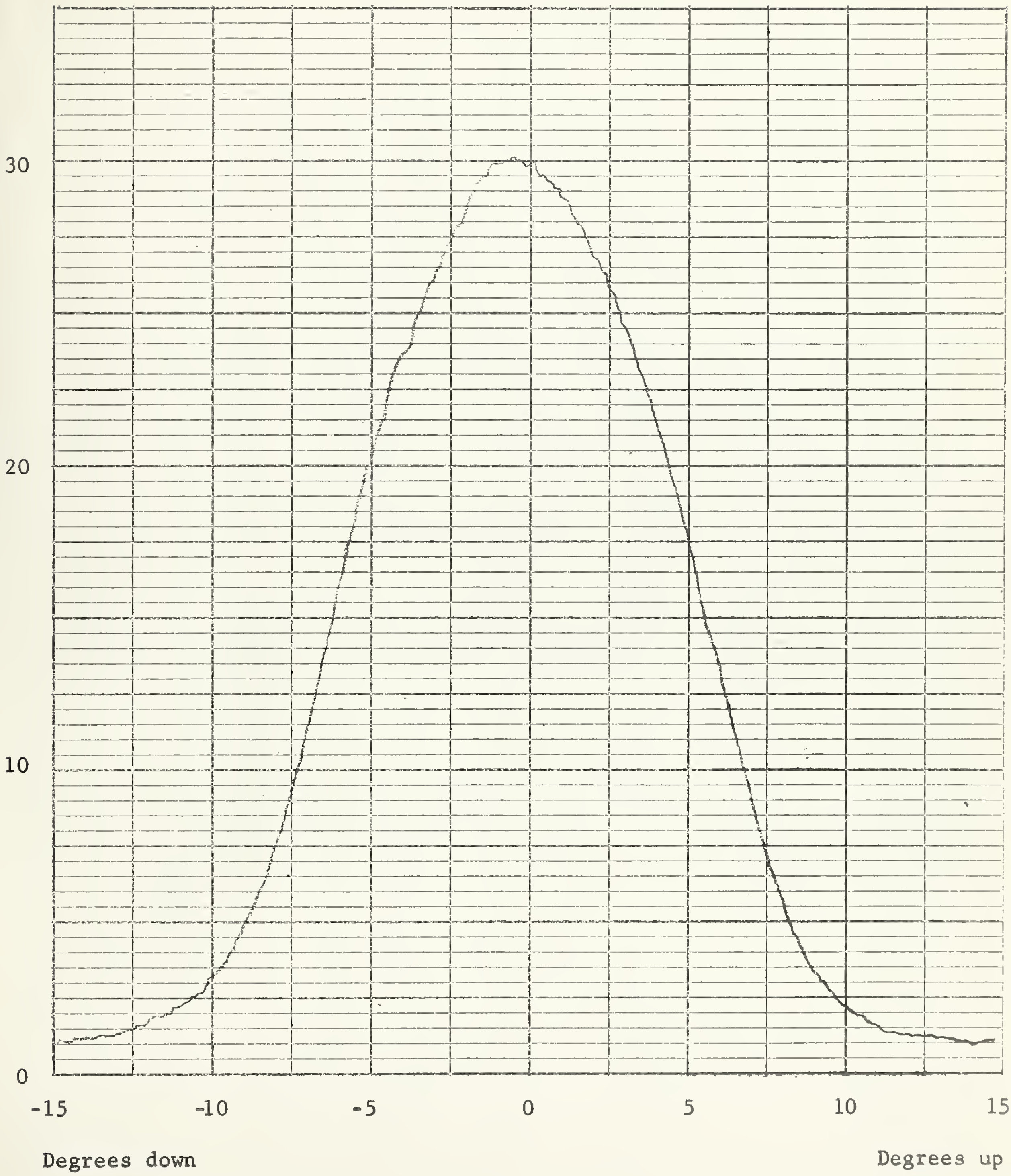

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Figure 3

Vertical Intensity Distribution

of a

Type 20A/PAR56Q/1 Lamp

(Lamp No. B4 from NBS Test 21P-44/62)

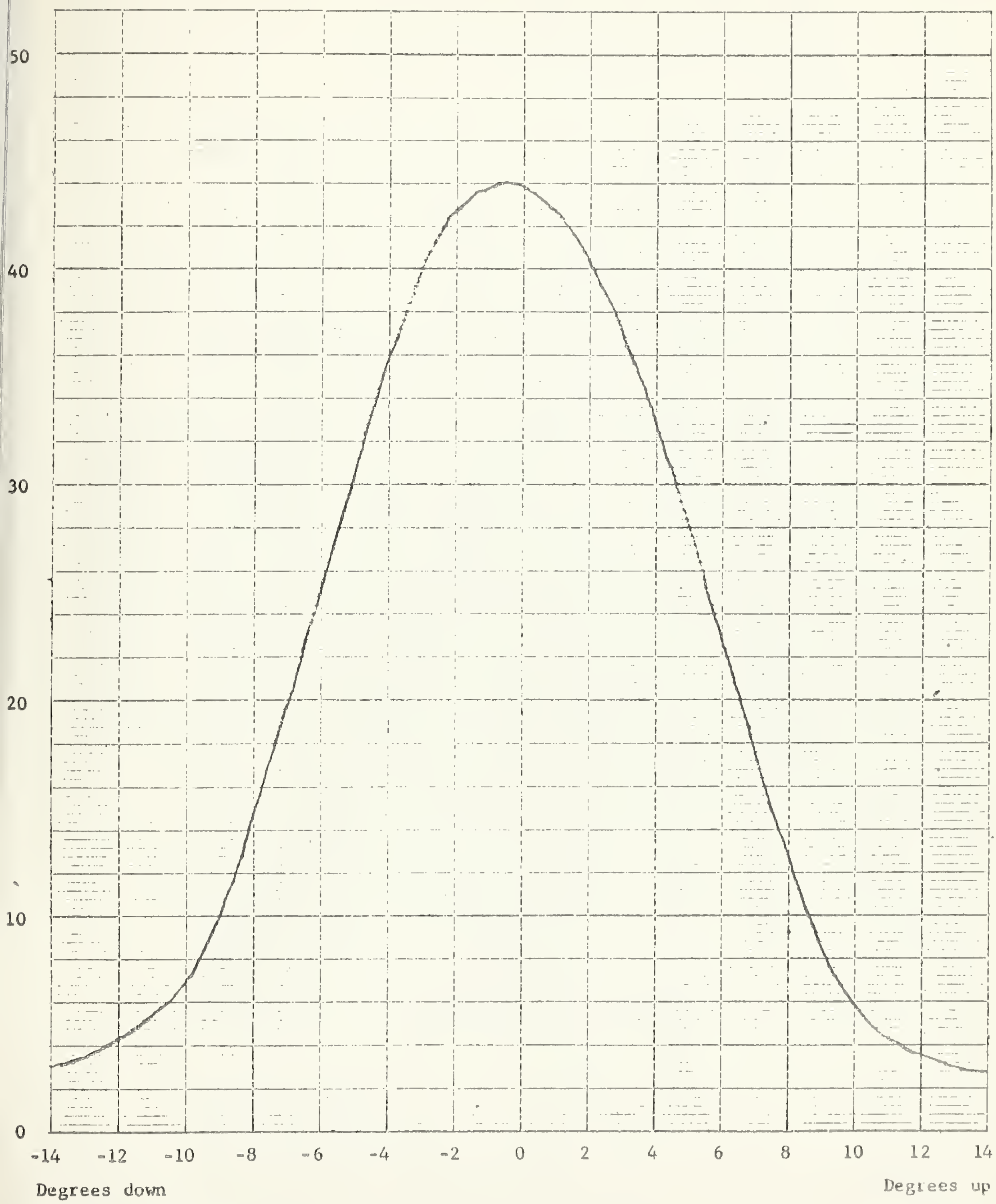

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Figure 4

Vertical Intensity Distribution

of a

Type 20A/PAR56/2 Lamp

(Lamp No. 4 from NBS Test 21P-4/61)

operated at rated current of 20 amperes

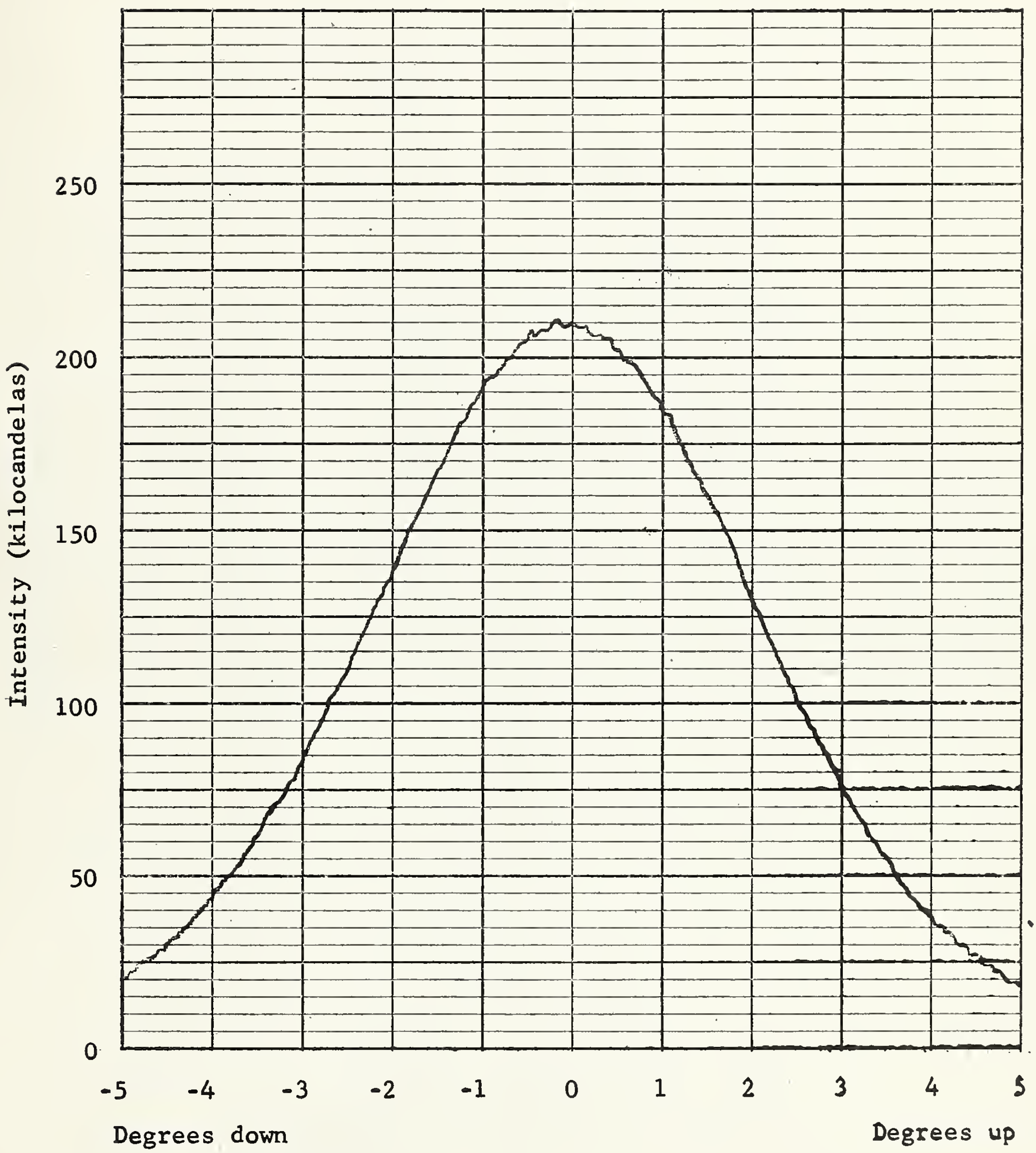

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Figure 5

Vertical Intensity Distribution

of a

Type 20A/PAR56Q/3 Lamp

(Lamp No. A3 from NBS Test 21P-44/62)

operated at rated current of 20 amperes

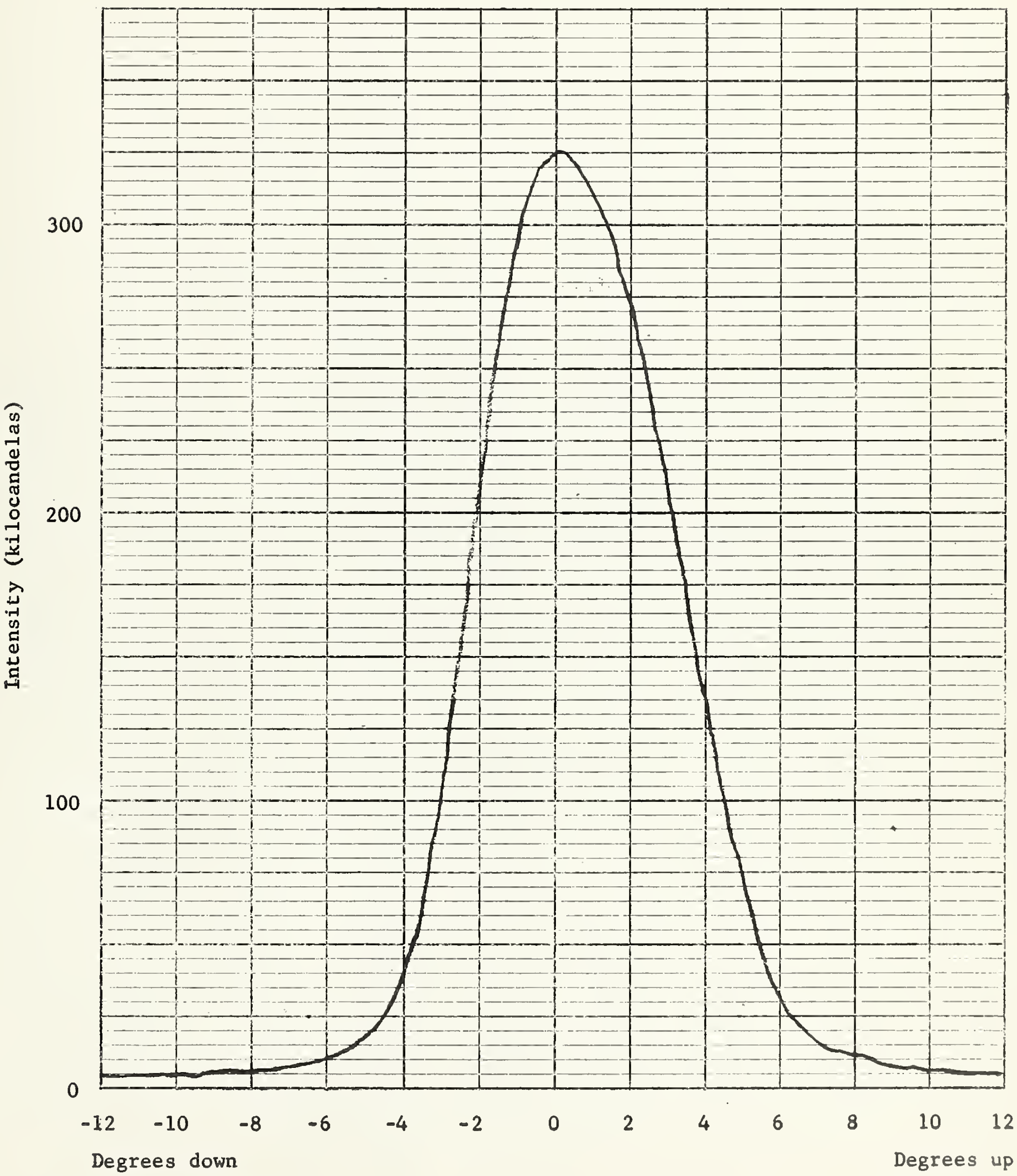

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Figure 6

Vertical Intensity Distribution

of a

Type 200PAR Locomotive Lamp

With CC-8 Filament

(Lamp No. 4 from NBS Report 6862)

operated at rated voltage of 30 volts

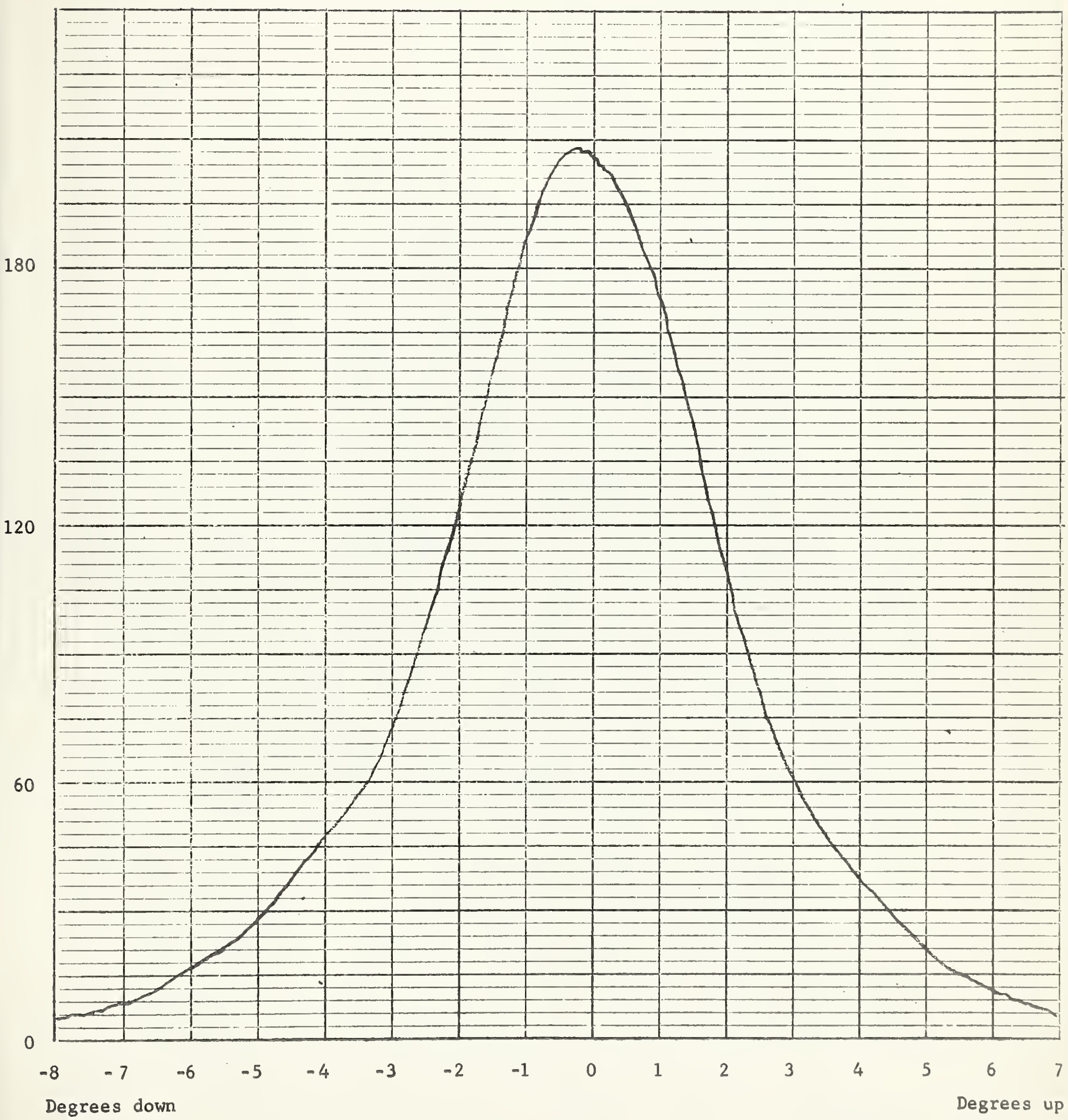

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Figure 7

Vertical Intensity Distribution

of a

Type 200PAR Locomotive Lamp

With C-13 Filament

(Lamp No. 1 from NBS Report 6862)

operated at rated voltage of 30 volts

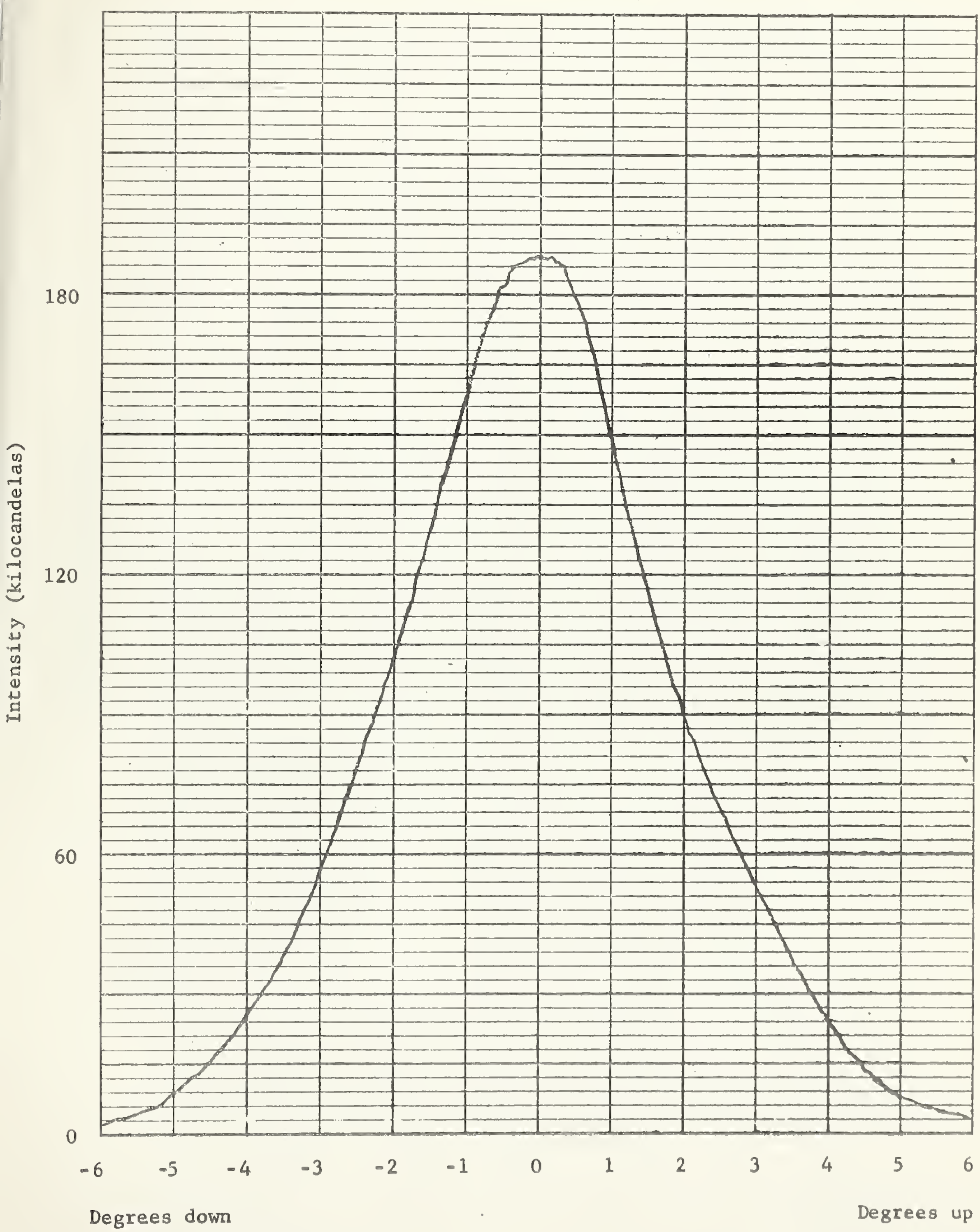

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Figure 8

Vertical Intensity Distribution

of a

Type 500PAR64/NSP Lamp

(Lamp No. 1N from NBS Test 21P-46/60)

operated at rated voltage of 120 volts

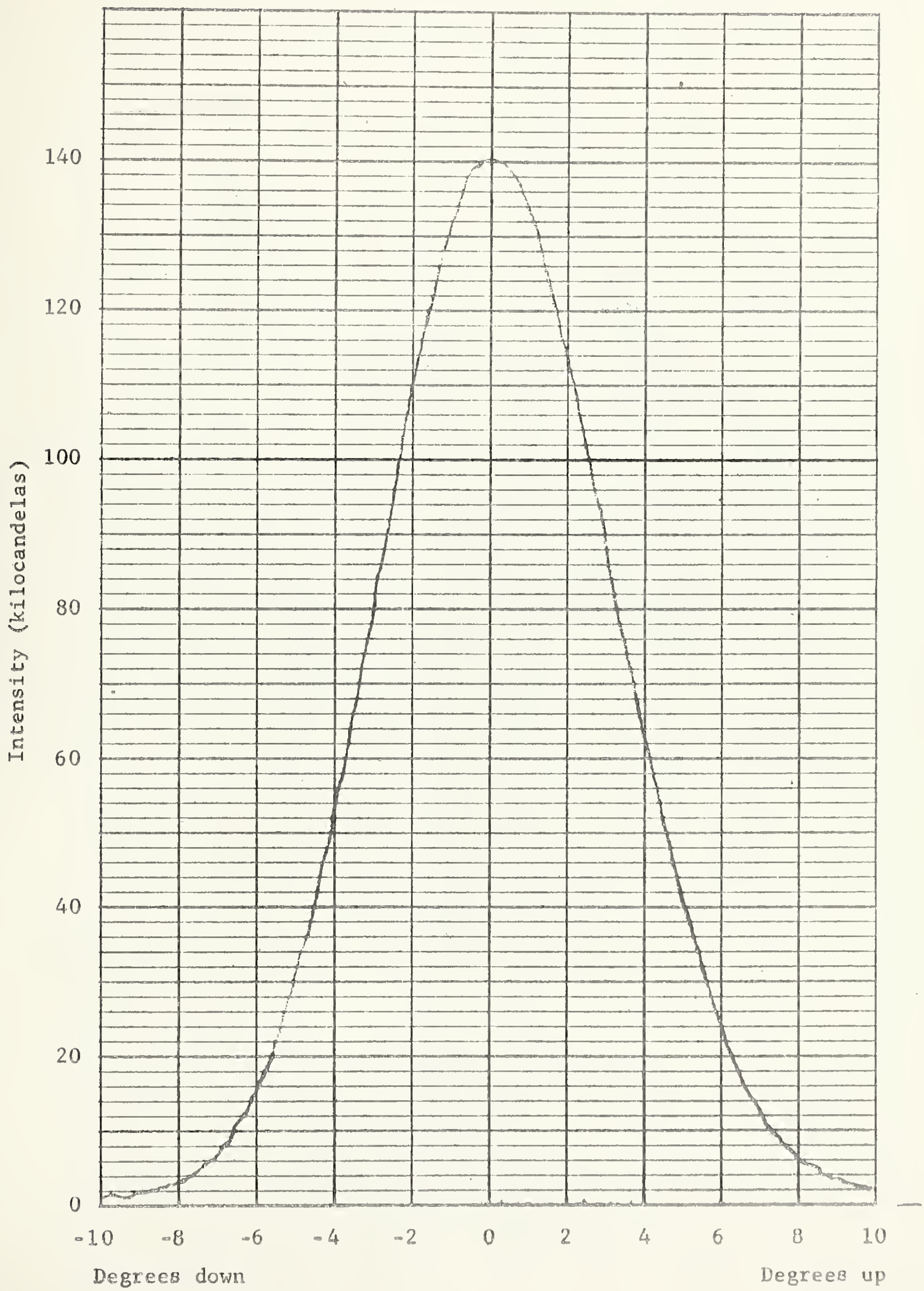

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Figure 9

Vertical Intensity Distribution

of a

Type 500PAR64/MFL Lamp

(Lamp No. 2M from NBS Test 21P-46/60)

operated at rated voltage of 120 volts

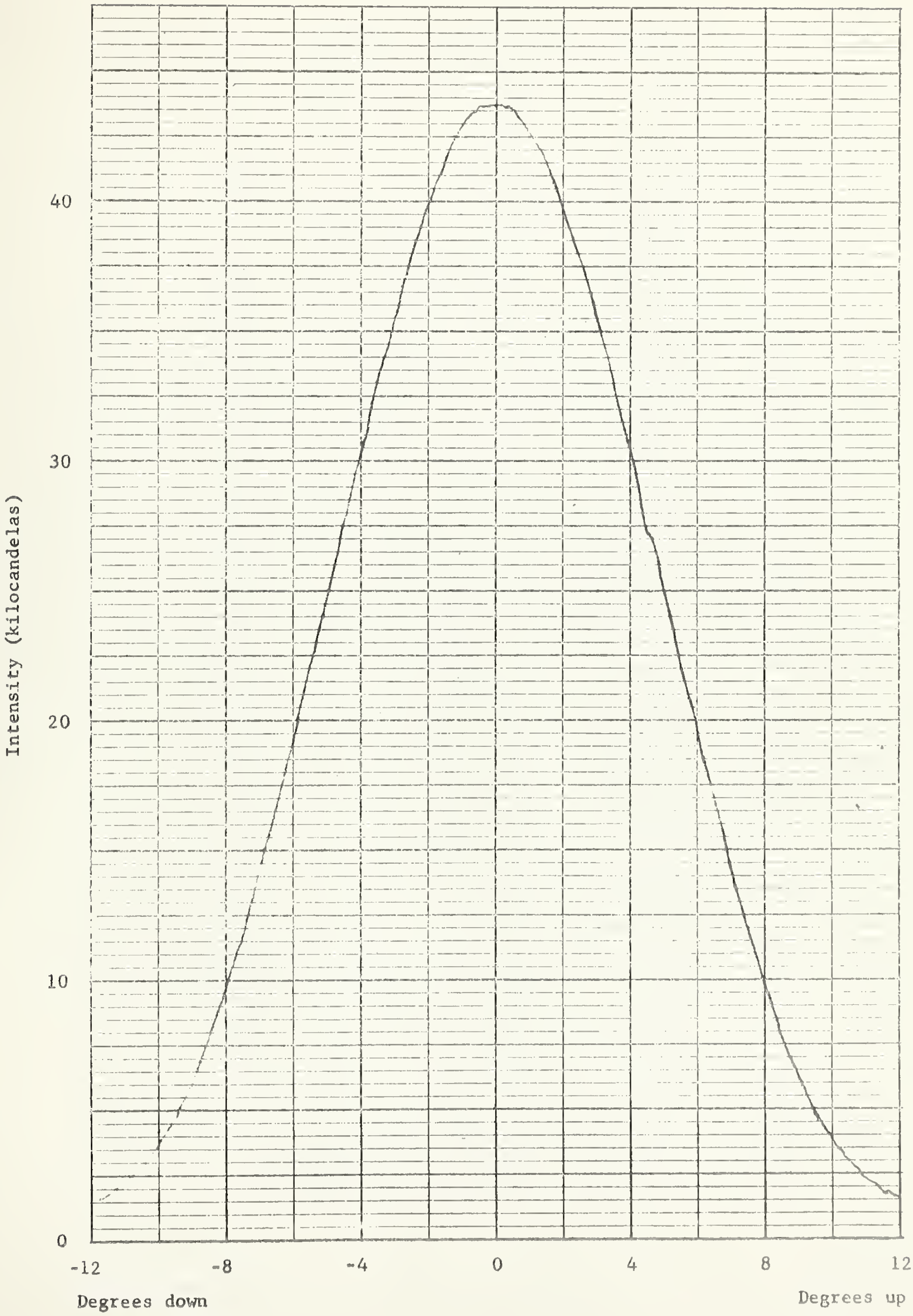

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Figure 10

Vertical Intensity Distribution
of a
Type 4519 Lamp
(Lamp No. 1 from NBS Test 21P-37/58)
operated at rated voltage of 13 volts

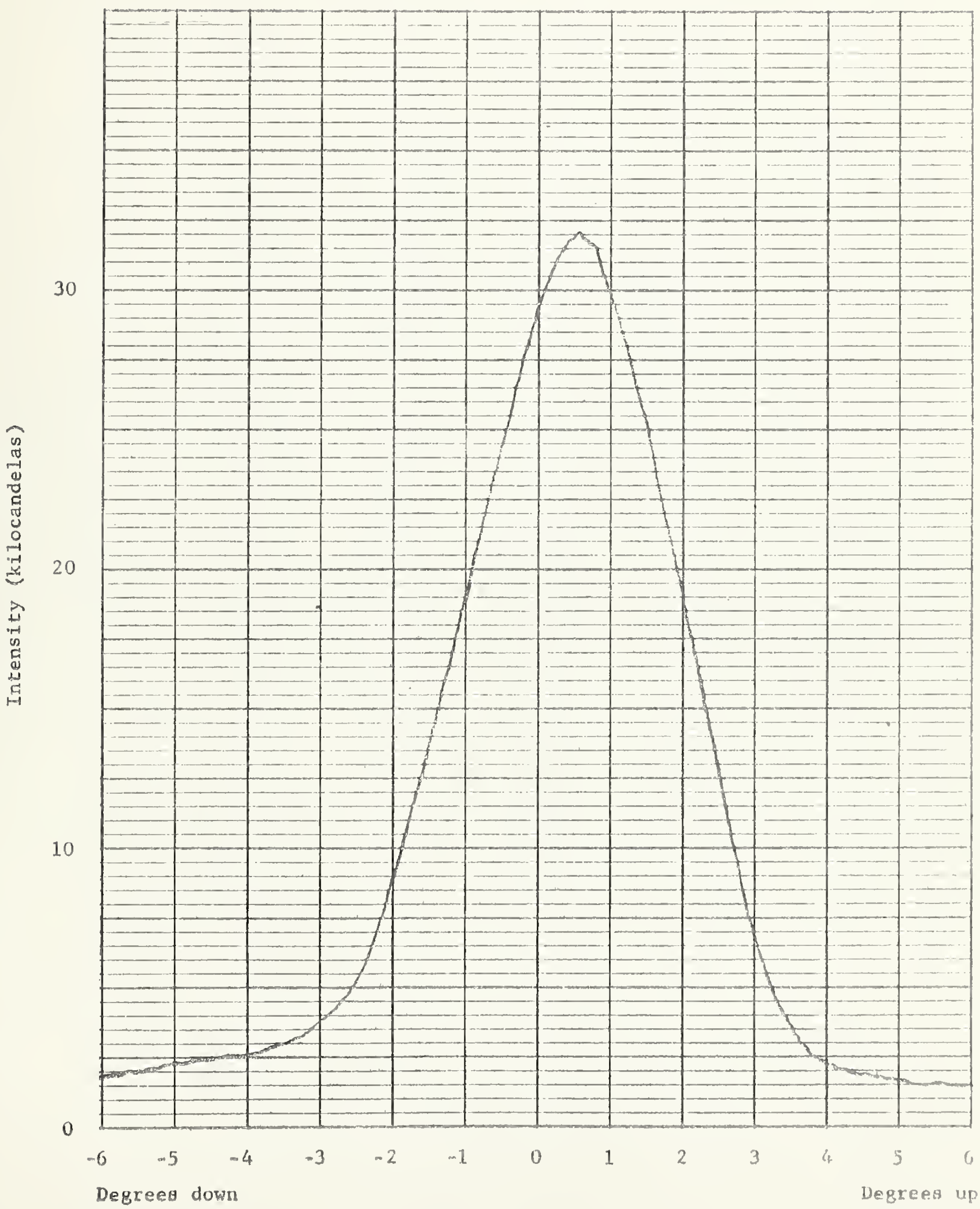

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Figure 11

Vertical Intensity Distribution

of a

Type 20A/PAR36/1 Lamp

(Lamp No. 1 from NBS Test 21P-17/58)

operated at rated current of 20 amperes

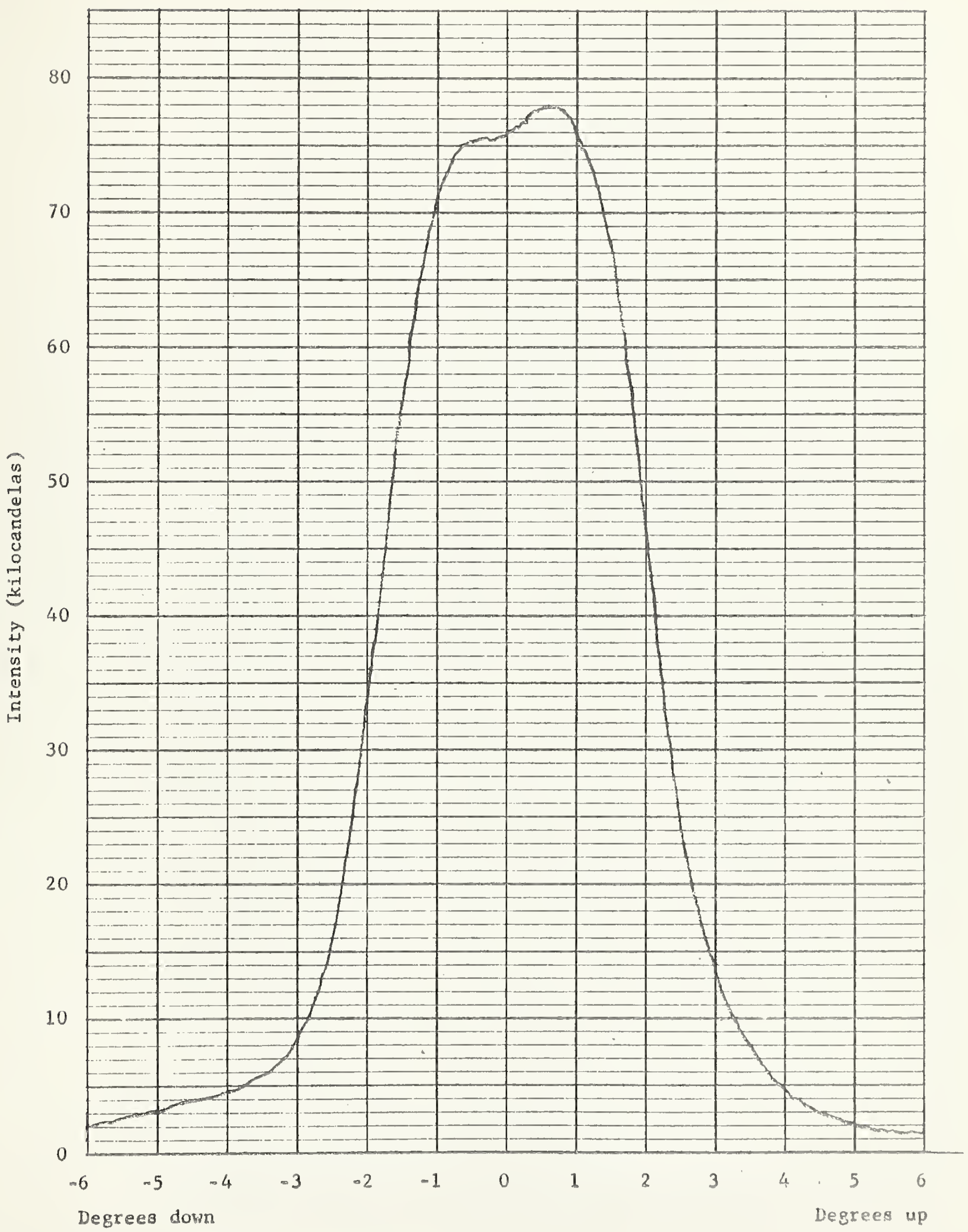

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Figure 12

Vertical Intensity Distribution

of a

Type 200PAR46/3NSP Lamp

(From NBS Memo Report Dated 8/9/61)

operated at rated voltage of 120 volts

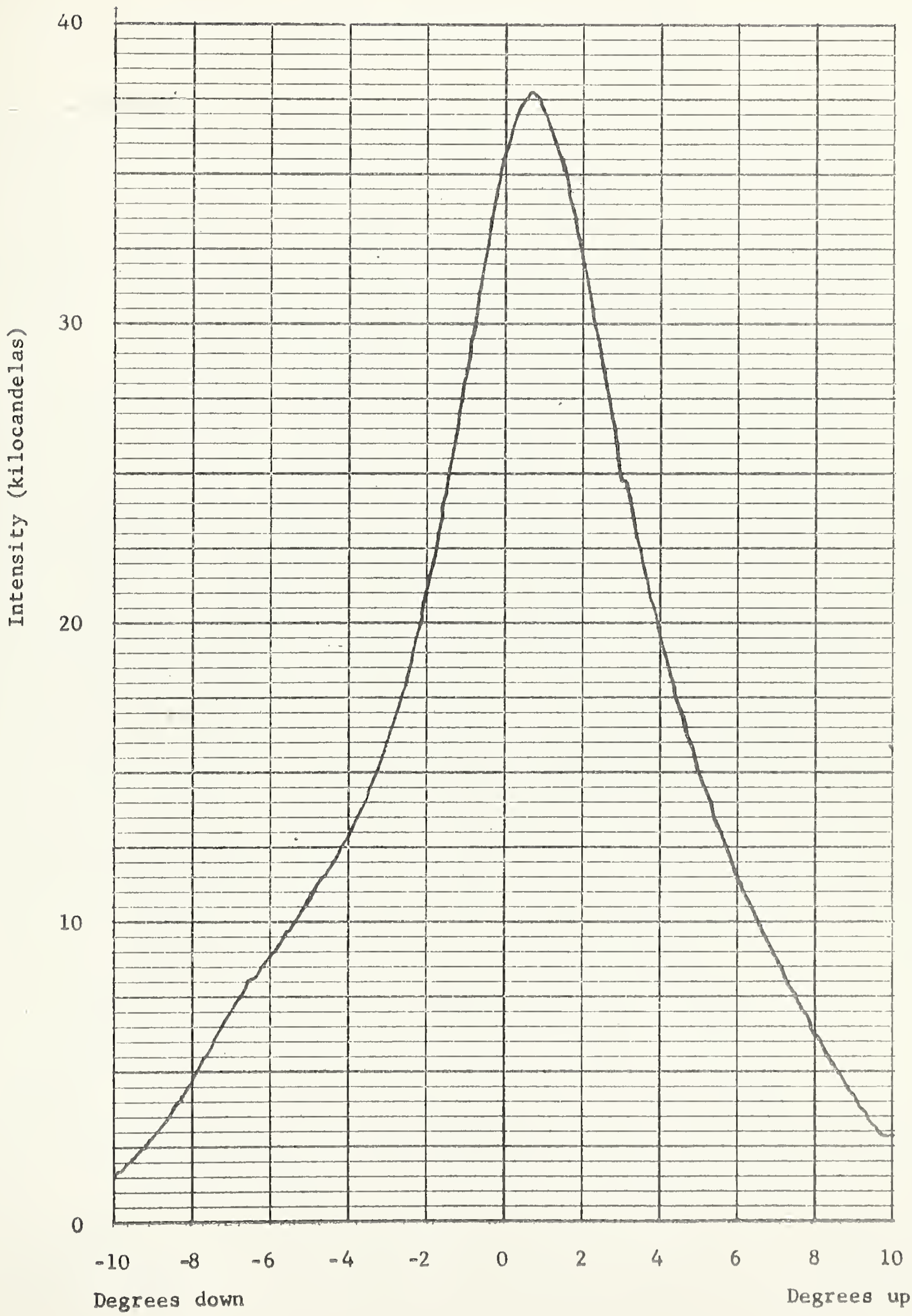

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Figure 13

Vertical Intensity Distribution

of a

Type 6.6A/PAR56/2 Lamp

(Lamp No. 200-2 from NBS Test 21P-3/56)

operated at rated current of 6.6 amperes

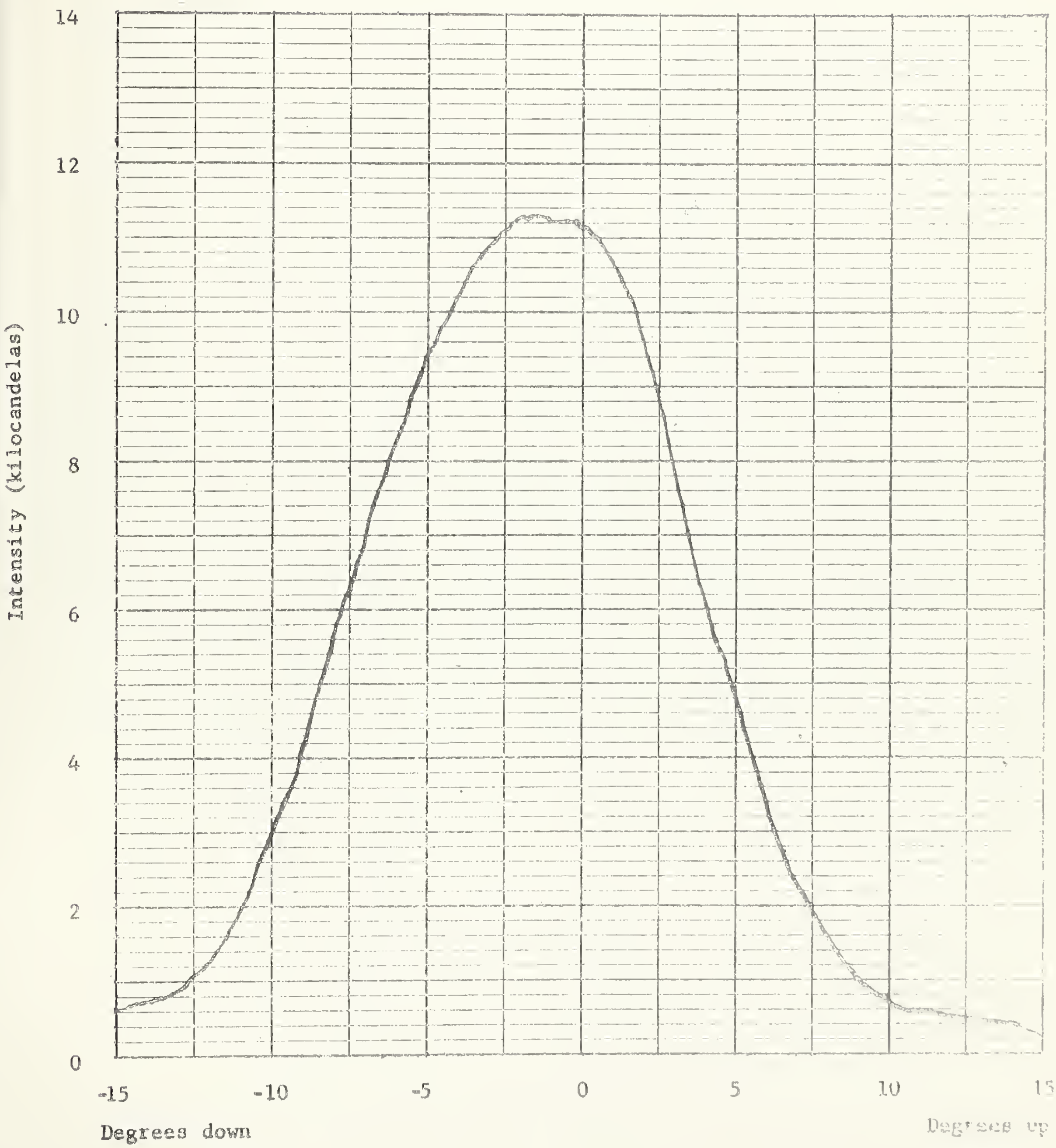

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Figure 14

Vertical Intensity Distribution

of a

Type 300PAR56/NSP Lamp

(Lamp No. 1 from NBS Report 5905)

operated at rated voltage of 120 volts

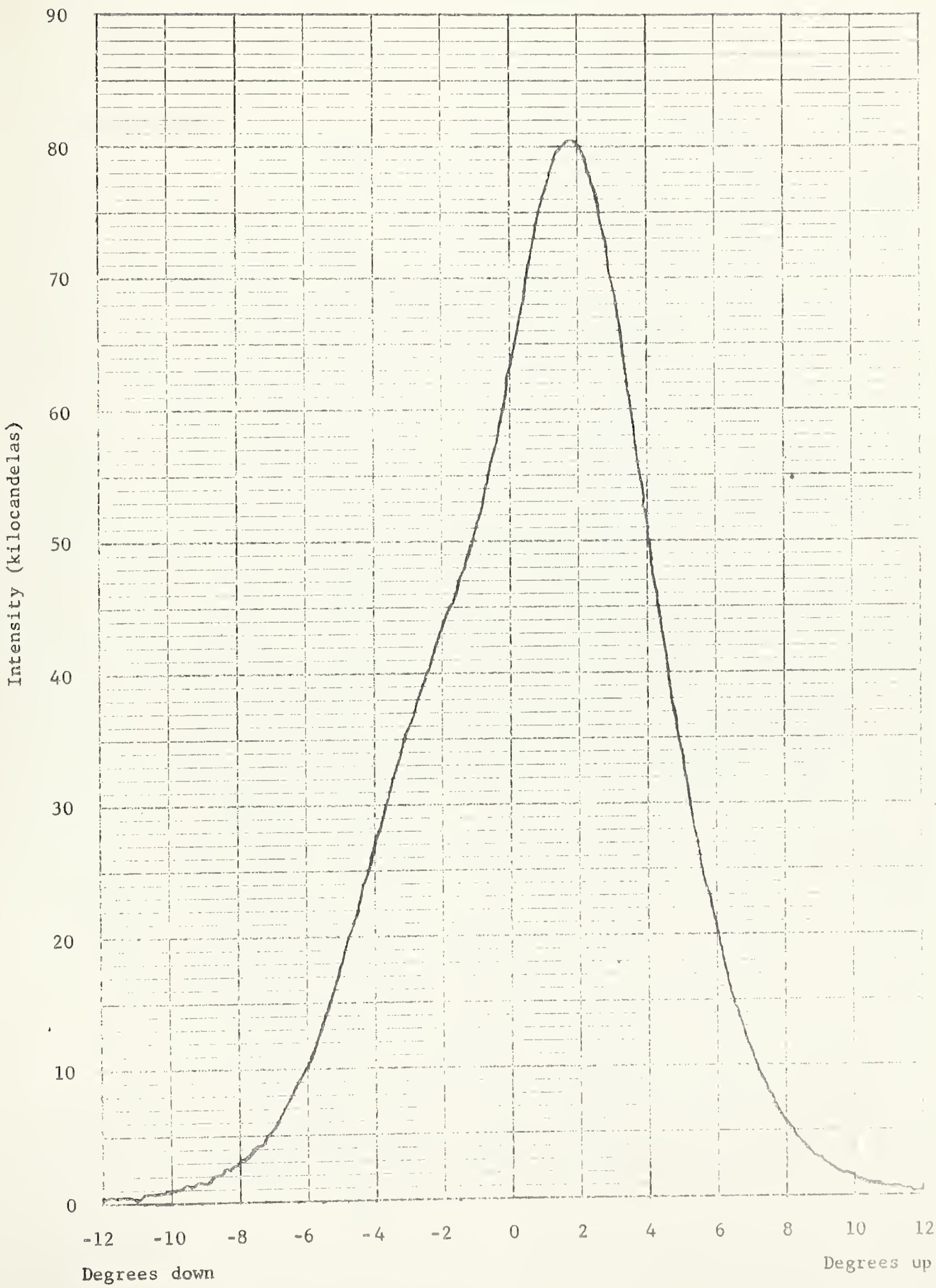

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Figure 15

Vertical Intensity Distribution
of a
Type 399PAR Lamp
(Lamp No. 11 from NBS Test 21P-6/54)
operated at rated voltage of 115 volts

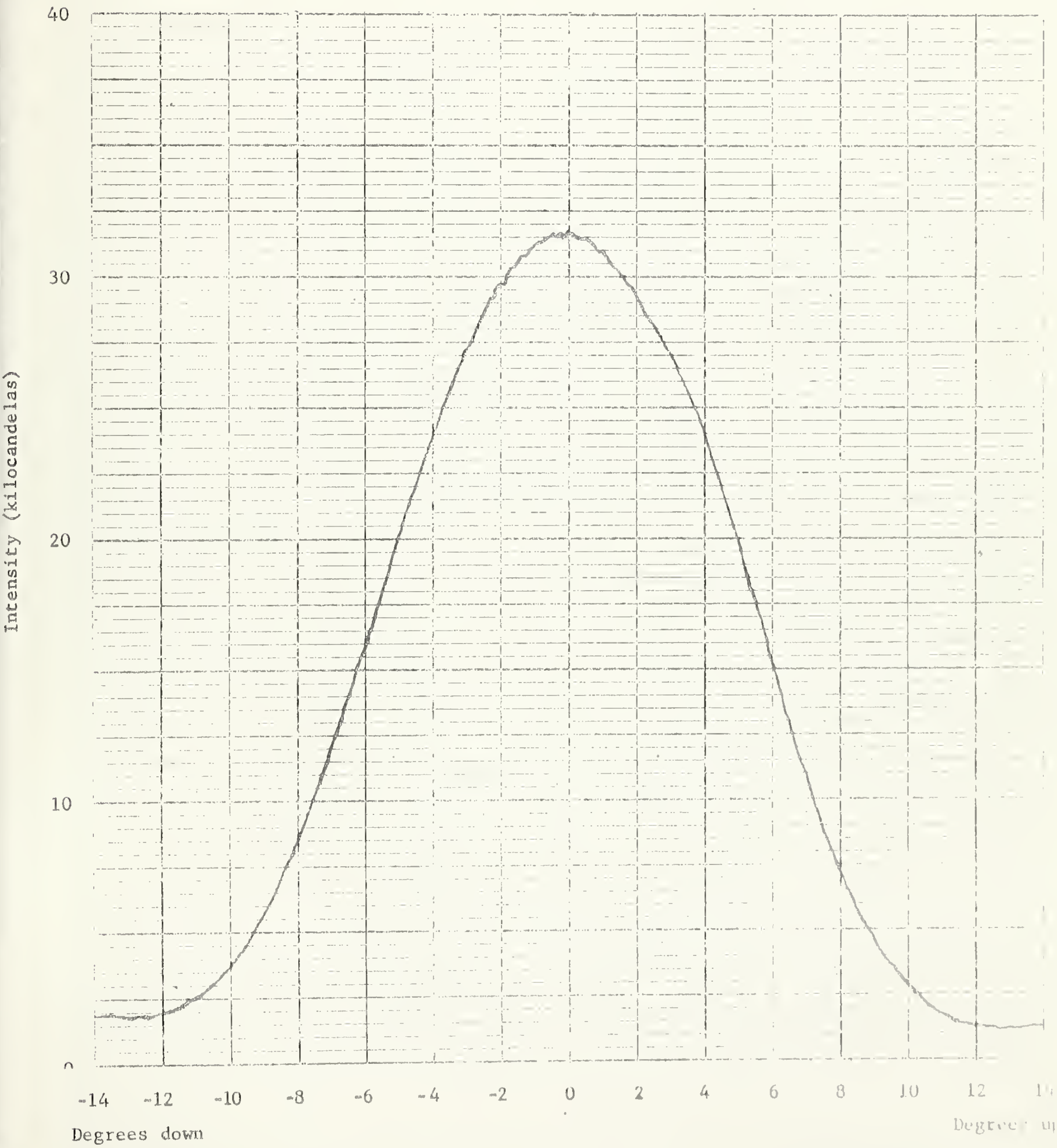

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Figure 16

Horizontal Intensity Distributions

of a

Type 200PAR46/3NSP Lamp

(From NBS Memo Report Dated 8/9/61)

operated at rated voltage of 120 volts

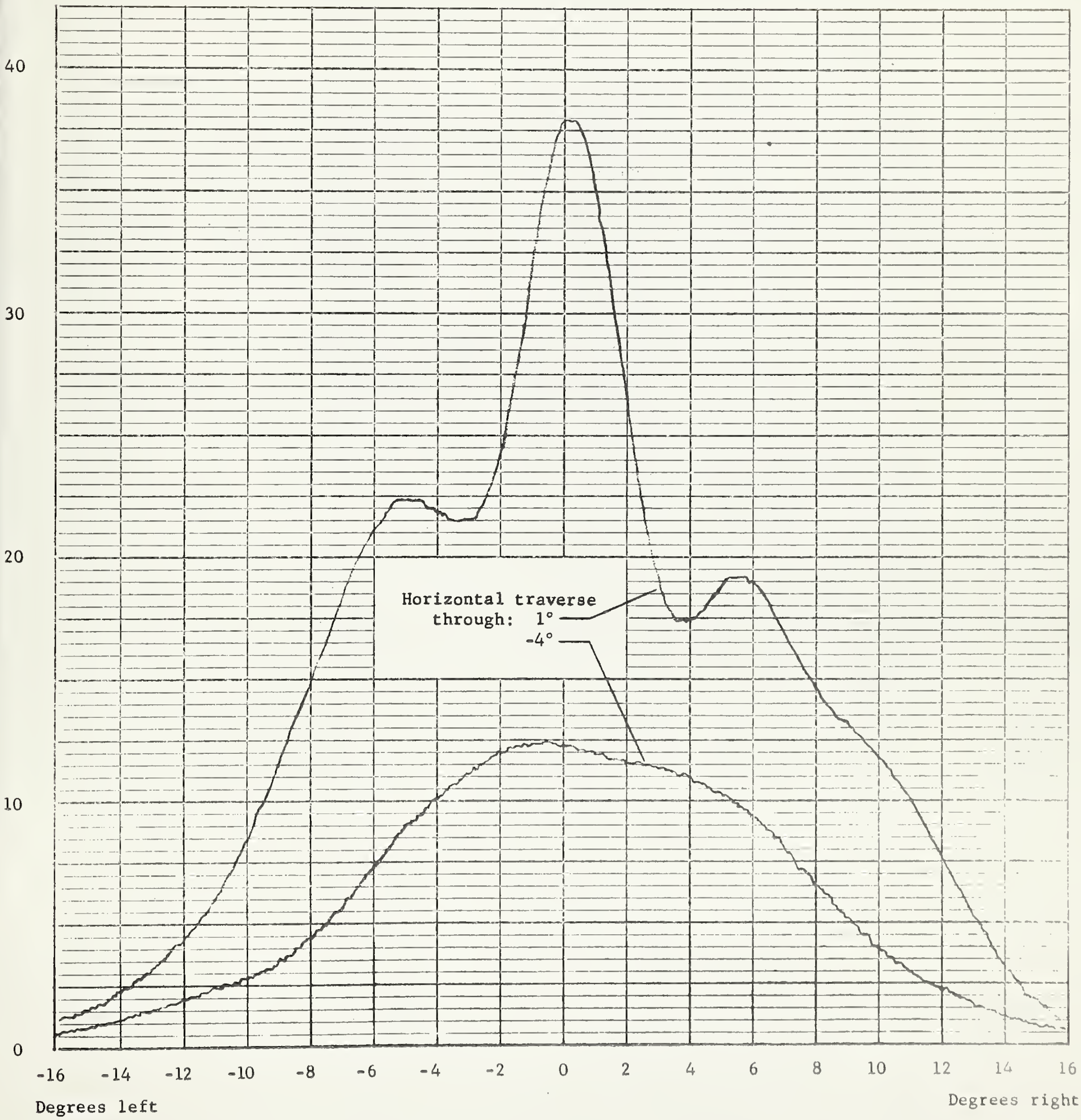

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Figure 17

DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS