NATIONAL BUREAU OF STANDARDS REPORT

5294

Photometer for the Measurement

of the

Effective Intensity of Condenser-Discharge Lights

By
C. A. Douglas

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Prepared for

Ship Installations Division
Bureau of Aeronautics

and

Equipment Laboratory
Wright Air Development Center

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ABSTRACT

This report describes a method of determining the effective intensity of flashing lights which produce flashes of short duration, e.g. condenser-discharge lights. By the use of this method it is possible to record effective-intensity distributions automatically. Examples of such distributions are included.

1. INTRODUCTION

In the past, measurements of the effective intensity of condenser-discharge lights have generally been made by two methods: (1) coupling the output of a phototube to a cathode-ray oscilloscope, photographing the trace of the instantaneous intensity against time, integrating the area under the curve and computing the effective intensity; and (2) charging a capacitor by the photoelectric current generated by one or more flashes and measuring the voltage developed with a vacuum-tube voltmeter. Both of these methods are time consuming when an intensity-distribution curve of a projector using a condenser-discharge lamp is desired. In addition, there is often uncertainty about the accuracy of the correction of the spectral response of the photometric system to the CIE standard observer luminosity function; the sensitivity may be so low that short photometric distances are required; and the phototube may be saturated during part of the flash destroying the linearity of the system. A method which will allow measurements of the effective-intensity distribution of condenser-discharge units to be made and recorded automatically is very desirable. The development of such a method using equipment available at the National Bureau of Standards is described below.

2. EFFECTIVE-INTENSITY PHOTOMETER

The effective-intensity photometric system is shown in figure 1. Light from either the test unit or the standard lamp falls on a diffusing glass so that the distribution of illumination on the photosensitive surface of the phototube is independent of the distance of the light source. A small aperture in front of this glass is used to control the illumination on the phototube. The light then passes through the luminosity filter to the phototube. This filter is so designed that the spectral response of the phototube-filter-diffusing glass combination is essentially that of the luminosity function of the CIE standard observer.

A type PJ-14B phototube is used because it is stable, has a low dark current, and its relatively flat spectral response simplifies the design of the luminosity filter.(1) The correction of the spectral sensitivity of the phototube is sufficiently accurate for the photometry of any "white" light. The output current of the phototube is smoothed by the resistance-capacitance network so that the d-c electrometer-amplifier will not be overloaded during the flashes and so that output current will be sufficiently stable to produce a smooth curve on the recording potentiometer. The output of the system is, of course, proportional to the average photoelectric current and hence to the average illumination at the phototube.

Note: The electrometer-amplifier was operated with the "GROUND" switch in the "I" position. With this arrangement, use of a single capacitor across the input of the instrument was unsatisfactory because the feedback in the instrument produced low-frequency oscillations (of the order of 0.1 to 0.5 cps) in the output. A network of the type shown eliminates these oscillations. With the "GROUND" switch in the "E" position a single capacitor across the input may be used. The time constant of the circuit is then a function of the capacitance across the input and the input resistance selected by the "INPUT RESISTANCE" switch. The arrangement shown is considered preferable unless very long time constants are required, for the time constant is relatively independent of the input resistance selected and may be readily adjusted by changing the values of R_1 and R_2. Ordinary carbon resistors are satisfactory but very high-leakage-resistance capacitors are required to obtain stability of calibration.

3. THEORY OF OPERATION

The method of obtaining the effective intensity of a condenser-discharge light flashed at a known rate from measurements of the average intensity is developed below.

3.1 Definition of Terms.

- I the instantaneous intensity of the test light during a flash
- $\bar{I}$ the average intensity of the test light during a complete flash cycle
- I_e the effective intensity of the test light
- I_s the intensity of the standard lamp
- T the transmittance of the sector disc
- D the distance between the test light and the diffusing glass of the photometer

(1) NBS Report 4421. Report on the Design and Calibration of a Remote-Indicating Photoelectric Brightness Meter. C.A.Douglas and I.Nimeroff.

d the distance between the standard lamp and the diffusing glass of the photometer

τ the time required for a complete flash cycle

R the recorder reading

R_s the recorder reading during calibration with the standard lamp.

3.2 Basic Relations

The effective intensity is defined as

$$I_e = \frac{\int_{t_1}^{t_2} I dt}{0.2 + t_2 - t_1} . \qquad (1)$$

The times t_1 and t_2 are generally chosen so that I_e is equal to I at these times.(2) However, the effective intensity is sufficiently small in comparison to the instantaneous intensity over most of the flash so that

$\int_{t_1}^{t_2} I dt$ may be replaced by $\int_{0}^{\tau} I dt$ without introducing significant errors. In addition the flash of a condenser-discharge light is so short (generally less than 0.001 second) that $t_2 - t_1$ is negligibly small in comparison to 0.2. Therefore,

$$I_e = 5 \int_0^{\tau} I dt. \qquad (2)$$

But

$$\bar{I} = \frac{\int_0^{\tau} I dt}{\tau} , \qquad (3)$$

therefore,

$$I_e = 5 \bar{I} \tau . \qquad (4)$$

Because of the time constant of the input circuit, the recorder responds to the average current of the phototube. During a flash the photoelectric current charges capacitor C_1 and the voltage across the phototube is not decreased appreciably. Hence the phototube does not saturate and the photoelectric currentis at all times proportional to the illumination on the phototube.

(2) NBS Report 4554. Computation of the Effective Intensity of Flashing Lights. C. A. Douglas.

Therefore, the recorder reading is given by

$$R = \frac{k \ \bar{I}}{D^2}, \tag{5}$$

where k is a constant of proportionality which is a function of the exposed area of the diffusing glass, the input resistance of the d-c amplifier, the range on which the amplifier is set, the load resistance across the output of the amplifier, and the sensitivity of the recorder.

Combining equations (4) and (5),

$$\frac{I_e}{R} = \frac{5 \gamma D^2}{k}. \tag{6}$$

For ease in interpretation of the recorder charts, the ratio I_e/R is made the product of either an integer, or the reciprocal of an integer, and an appropriate power of ten by adjusting the parameters of the circuit to obtain the proper value of k. The recorder chart can then be graduated in a convenient number of effective candles per chart division.

3.3 Calibration.

The calibration of the photometric system to obtain the proper value of k is accomplished by means of a standard lamp.

Since $$R_s = \frac{kI_s T}{d^2}, \tag{7}$$

$$R_s = 5\gamma D^2 \ \frac{R}{I_e} \cdot \frac{I_s T}{d^2}. \tag{8}$$

A value of I_e/R is chosen and the parameters of the photometric system are adjusted to obtain the desired R_s. The aperture of the photometer is kept sufficiently small that the phototube will not be saturated during a flash. The electrometer-amplifier is generally operated on the 100- or 300- millivolt range using an input resistance of 10^7 or 10^8 ohms. The maximum output of the instrument is kept near, but below, the design maximum. Final adjustment of the calibration is obtained by adjusting the value of the resistor, R_1, across the output of the amplifier until the voltage drop across this resistor drives the recorder to the desired reading, R_s.

3.4 Performance Tests.

The photometric system was calibrated by means of standard lamp NBS 790 (631 candles) one meter from the photometer and two 2-aperture

sector discs having transmittances of 0.0098 and 0.0252. These sector discs were used as designed and also with one aperture blocked. The discs were driven at speeds of 80 rpm and greater. Under these conditions the variation of the illumination on the photometer with time approximates that obtained with condenser-discharge lamps. No measurable change of response with variation in speed of rotation of the sector discs was found. The variation of output agreed with the computed changes in transmittance of the sector discs within the accuracy with which the recorder chart could be read.

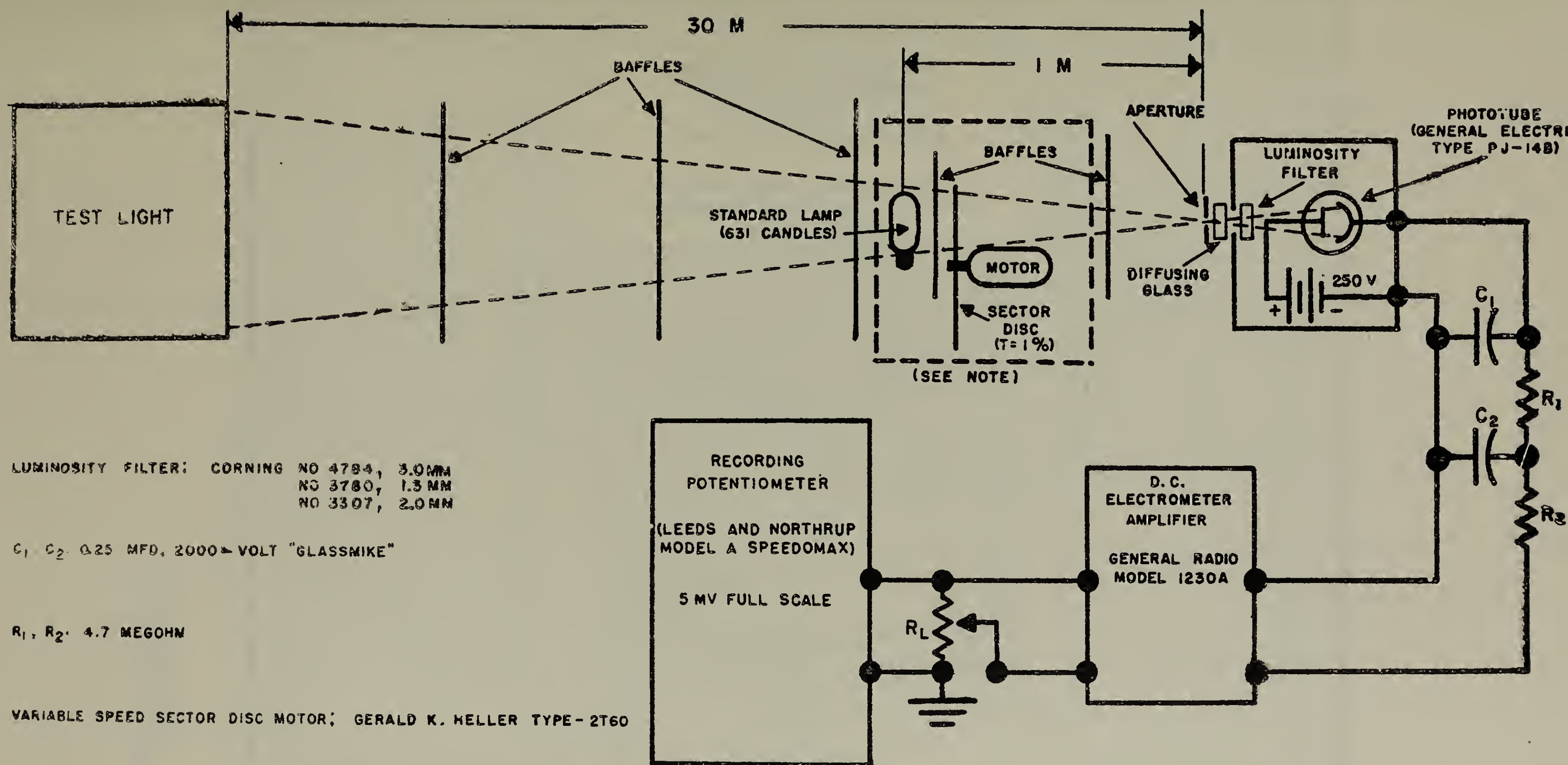
Measurements have been made automatically of the intensity distributions of a number of projectors using condenser-discharge lamps. The light under test was mounted on a goniometer to permit rotation about a fixed horizontal axis perpendicular to the photometric axis and about a secondary axis perpendicular to the first and initially vertical. These angles are referred to as "vertical" and "horizontal" respectively. Traverses were taken by driving the goniometer and the recorder-chart drives with synchronous motors, thus recording the intensity of the light as a function of the angle from the axis of the light. The speed of the goniometer drive was 7.5° per minute. This speed was sufficiently slow that the photometric system could follow the changes in intensity even with the long time constant introduced by the smoothing network in the input circuit to the d-c amplifier.

Examples of these measurements are shown in figures 2 and 3. As indicated in figure 2, when the flash rate is two per second, the time constant of the photometric system is sufficient to smooth the curves so that the individual flashes are not shown. However, as shown by figure 3, when the flash rate is one per second, the effect of the individual flashes is visible. This effect could have been reduced by increasing the value of R_1 and R_2. However, the time constant would then have been so long that the scan rate of the goniometer would have had to be considerably slower than the 7.5 degrees per minute which was used in order that the photometric system follow the changes in intensity with angle of view.

4. DISCUSSION

The photometer system described here is, of course, not limited to the photometry of condenser-discharge lights only, but is applicable to any light having a flash duration of less than about one millisecond (between the times when the intensity is about 5% of peak intensity). The effective intensity distributions of lights with flash durations somewhat longer than one millisecond (about 0.01 second) can often be recorded automatically with this system if a suitable correction factor is included in the calibration. This factor is the ratio of the effective intensity computed by equation (1) to that computed by equation (2).

The components used in the system described here can, of course, be replaced with components having similar characteristics. Those listed in figure 1 were used because they were readily available.



LUMINOSITY FILTER: CORNING NO 4784, 3.0MM
NO 3780, 1.3 MM
NO 3307, 2.0 MM

C_1, C_2: 0.25 MFD, 2000-VOLT "GLASSMIKE"

R_1, R_2: 4.7 MEGOHM

VARIABLE SPEED SECTOR DISC MOTOR; GERALD K. HELLER TYPE-2T60

COMPONENTS WITHIN THE DOTTED LINES ARE IN PLACE ONLY DURING CALIBRATION

R_L, CALIBRATION ADJUSTING RESISTOR; DECADE BOX 9 X (10+1+0.1+0.01)

EFFECTIVE-INTENSITY PHOTOMETRIC SYSTEM

NBS

FIGURE-1

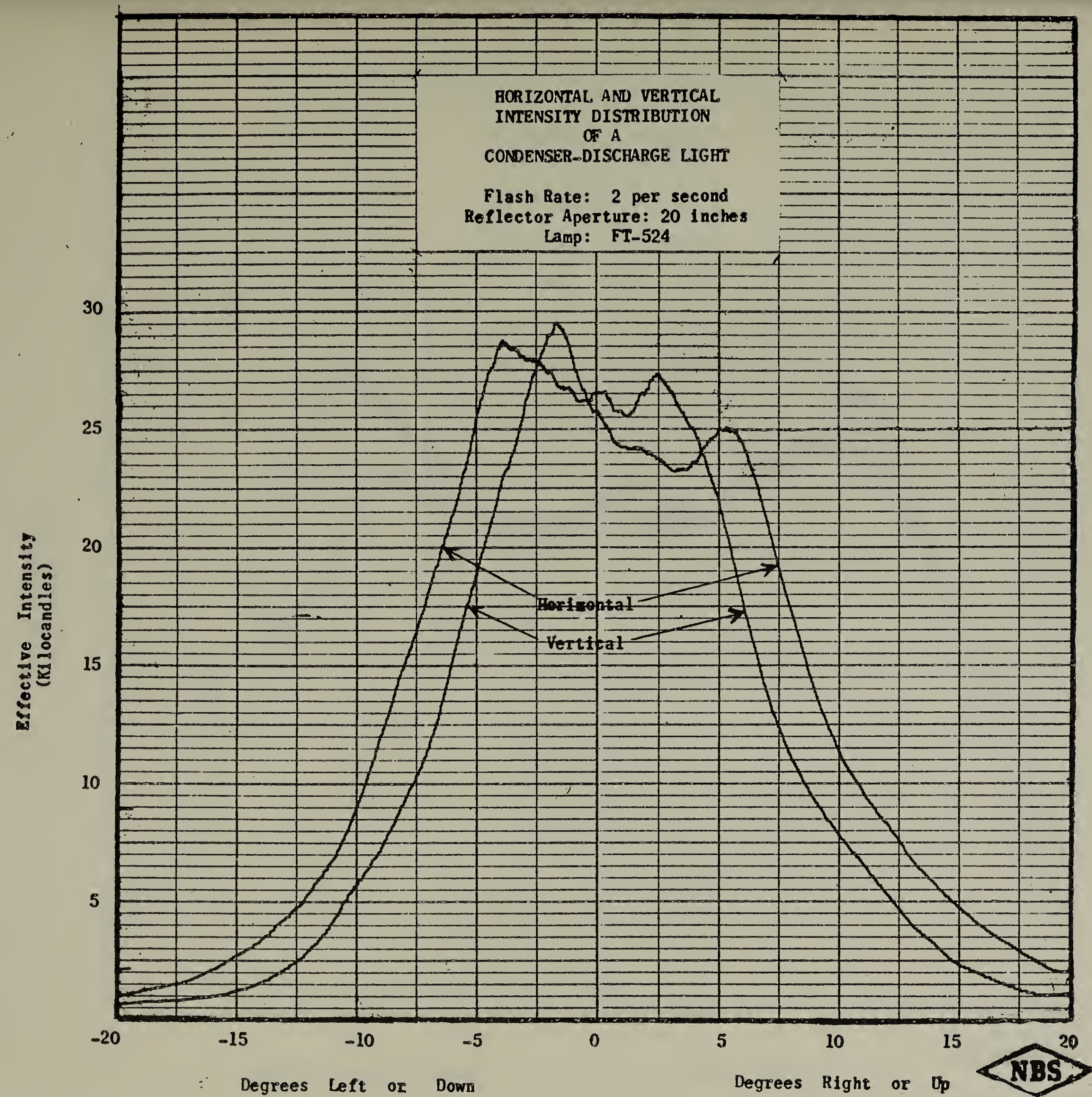

HORIZONTAL AND VERTICAL
INTENSITY DISTRIBUTION
OF A
CONDENSER-DISCHARGE LIGHT
Flash Rate: 2 per second
Reflector Aperture: 20 inches
Lamp: FT-524
Horizontal
Vertical
Effective Intensity
(Kilocandles)
30
25
20
15
10
5
-20
-15
-10
-5
0
5
10
15
20
Degrees Left or Down
Degrees Right or Up
NBS

Figure 2

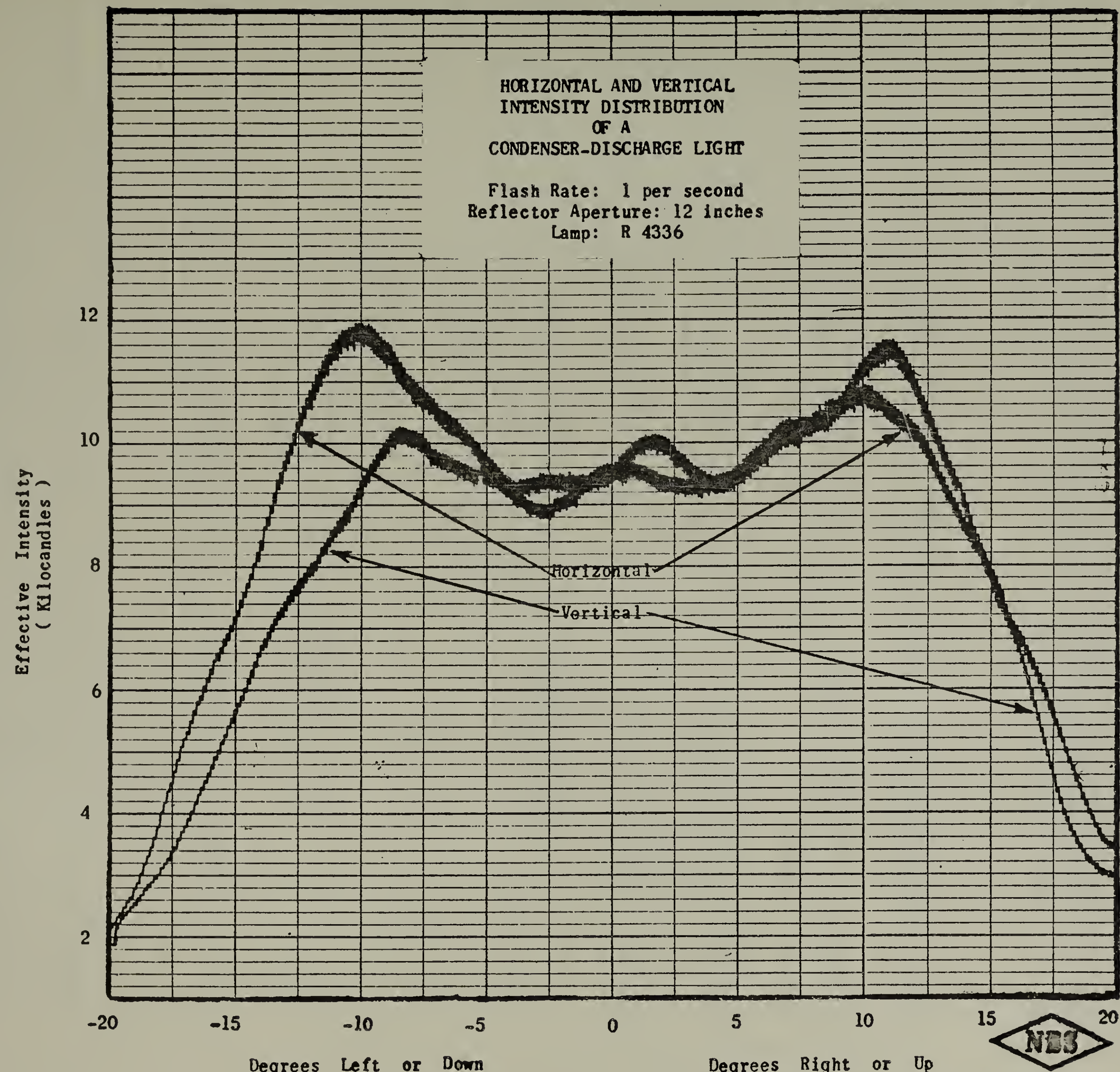

HORIZONTAL AND VERTICAL
INTENSITY DISTRIBUTION
OF A
CONDENSER-DISCHARGE LIGHT
Flash Rate: 1 per second
Reflector Aperture: 12 inches
Lamp: R 4336
Effective Intensity
(Kilocandles)
12
10
8
6
4
2
Horizontal
Vertical
-20
-15
-10
-5
0
5
10
15
20
Degrees Left or Down
Degrees Right or Up
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Figure 3

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

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Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

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